DEPARTMENT OF DEFENSE APPROPRIATIONS FOR FISCAL YEAR 2022

TUESDAY, APRIL 13, 2021

U.S. SENATE,
SUBCOMMITTEE OF THE COMMITTEE ON APPROPRIATIONS,
Washington, DC.

The subcommittee met at 10:02 a.m. in room SD–192, Dirksen Office Building, Hon. Jon Tester (chairman) presiding.

Present: Senators Tester, Durbin, Baldwin, Shaheen, Shelby, Moran, and Hoeven.

DEPARTMENT OF DEFENSE

DEFENSE INNOVATION AND RESEARCH

STATEMENT OF Ms. BARBARA McQUISTON, PERFORMING THE DUTIES OF THE UNDER SECRETARY OF DEFENSE FOR RESEARCH AND ENGINEERING

OPENING STATEMENT OF SENATOR JON TESTER

Senator TESTER. We'll call this committee to order.

I want to start by telling everybody here what an honor it is to serve as chairman of this committee and with Senator Shelby, a true gentleman, and I also want to thank Dick Durbin for his longtime leadership on this committee, something that I have appreciated as a member and I have continued appreciation for his role as Whip and the chairman in the caucus, and so thank you, Senator Durbin.

Today, we have Ms. McQuiston, and Dr. Tompkins virtually. Thank you all for being here today, and I want to thank you for your ongoing hard work to lead and shape the Department of Defense Innovation and Modernization efforts.

When it comes to Federal funding priorities, few things are more important than innovation and research, and it is critical for Congress to continue to make strong research investments across the board.

America is facing many difficult and evolving national security challenges right now. We have heard from combatant commands in recent weeks about the daily threats they face, particularly from Admiral Davidson, the Commander of the Indo-Pacific Command.

In this subcommittee, it is critical that we do our best to ensure our service members continue to have access to the world's most sophisticated and advanced technologies. So I hope to hear the witnesses' perspective on the global race for innovation, particularly as we compete with China and Russia, and I look forward to learning

more about ongoing and future DOD (Department of Defense) technology innovation efforts and whether it has the tools and resources it needs to work with various partners across the country and that includes taking advantage of the incredible innovations happening across this country, including those at small businesses who can often bring fresh ideas, nimble operations, and cutting edge inventions to the table.

With that, I will turn to Ranking Member Shelby for his comments.

Senator Shelby.

STATEMENT OF SENATOR RICHARD C. SHELBY

Senator SHELBY. Thank you, Mr. Chairman. Thank you for this hearing. I think it's very important to have a hearing with DARPA (Defense Advanced Research Projects Agency). Welcome.

This committee has approved billions of dollars, Mr. Chairman, for basic research, applied research, and advanced technology development to support efforts that would allow our military to maintain a competitive advantage and strategic advantage over our adversaries.

Our technological and industrial progress remains a constant target from China and Russia and other nation states that are actively working to undermine and surpass our military's advancements. I believe we need a ready and lethal force equipped with modernized systems capable of providing strong national security and, importantly, deterring war. Our investments in innovative research are critical in guaranteeing success here.

Over the last 4 years, this committee has supported the necessary budget increases in cutting edge research areas, such as hypersonics, artificial intelligence, unmanned systems, and microelectronics to address warfighter needs and capability gaps, and with the top-line budget recommendations unveiled by the current Administration last week, I'm currently concerned about our ability to continue to make those essential strategic investments that will allow us to keep pace.

I look forward to hearing from the witnesses today about the progress being made in innovation and technology within the Department of Defense and how resource constraints may impact the department's ability to field cutting edge technology in the future.

I also recognize that we're significantly constrained from getting into many of the details here today that would provide for a comprehensive discussion in an open hearing setting.

Perhaps, Mr. Chairman, I've suggested that we consider a classified discussion with DARPA at a later date when you can have it because what DARPA is doing is important to all of us and especially to our Armed Forces.

Thank you, Mr. Chairman.

Senator TESTER. Absolutely, Senator Shelby, and we will take that up. We'll make that happen.

I would recognize Ms. McQuiston for a statement. You have 5 minutes. There is a Memorial Service at 11. So I'd ask you to try to keep your comments to 5 minutes and so we can get some questions. The rest of your statement for sure, your full statement will be a part of the record. So you have the floor.

SUMMARY STATEMENT OF MS. BARBARA MCQUISTON

Ms. MCQUISTON. Chairman Tester, Ranking Member Shelby, and Members of the Subcommittee, thank you for providing this opportunity to testify——

Senator TESTER. You need to turn your mike on, please.

Ms. MCQUISTON. I apologize. Is it on?

Senator TESTER. Bring it closer to your mouth. It might help.

Ms. MCQUISTON. It's not lighting up. Okay. I apologize.

Chairman Tester, Ranking Member Shelby, and Members of the Committee, thank you for providing this opportunity to testify before you today. It's an honor to be here alongside my friend and colleague, Dr. Stefanie Tompkins, Director of DARPA.

I'm truly honored to represent the Research and Engineering Workforce. I'm also excited to return to public service. I began my first government tour in 2006 at DARPA and today I return to public service performing the duties of Under Secretary overseeing DARPA as well as DIU MDA Space Development Agency Service Labs, Direct Prototyping and Experimentation.

R&E serves as the chief technology officer for the Department of Defense, strengthening national security and boosting economic security. Investments in science, technology, and innovation today can pay dividends tomorrow.

When I first started at DARPA, scientists were conducting research in vaccine technology. Today, those discoveries have contributed to the success of the COVID–19 vaccines. I'm quite excited and proud that we are all benefiting from past investments as we address the global pandemic. This is just one example of the tremendous impact DOD investments have not just for our military but for our Nation as a whole.

To continue this track record of success, we must reaffirm our commitment to science, technology, and innovation today to guarantee a strong tomorrow. This strategy for the future is critical because our competitors are moving quickly.

The use of drones in the recent conflict between Azerbaijan and Armenia may foreshadow things to come as others move more quickly to adopt cheap emerging technology.

As both Secretary Austin and Deputy Secretary Hicks have stated, the People's Republic of China is a pacing challenge to the U.S. military. Bringing new technology and innovations will be central to meeting that challenge. Presenting a credible deterrent to potential adversaries requires us to develop and field emerging technologies.

We must innovate at speeds and scale. Success requires more than a go-it-alone approach. We must explore more flexible partnerships with the private sector and academia, with small businesses and HBCUs (Historically Black Colleges and Universities). We must reinvigorate our Federal research capabilities, elevate science, promote technology, and expand partnerships with our allies.

R&E is committed to overcoming the value of death. We've shown that innovation and modernization can be done faster with more flexibility and commercial opportunities. From low-cost expendable drones to safer ion batteries, we must strive to eliminate

gaps in planning or funding that can leave a project sitting on the shelf for years. We must do more to engage the services from day one.

Our competitors and potential adversaries will not wait for our planning and budget cycles. We must balance oversight with the need to move quickly in order to maintain our advantages. This last year has demonstrated the importance of supply chains. The President and Congress have made it clear that onshoring the supply chain for microelectronics is critical to our national and economic security. The department has been taking actions to make microelectronics trustworthy, available, and sustainable.

When I joined the government labs, our labs are the premier place to work. Although we employ some of the best and brightest minds, we are losing talent to the private sector and competitors. The hiring flexibility Congress has recently given to the department are helping, but we need to do more.

One bright spot I want to highlight is DOD Bush Faculty Member John Rogers who pioneered the new field of bioelectronics. Rogers' research was the foundation of a new class of stretchable electronic devices. This research led to the 2020 release of a new flexible skin patch that can track a person's health through sweat. It allows for wearable devices to detect whether someone has COVID–19. His company is award-winning and moving to commercialize the sensors based on this research.

While I'm optimistic about R&E's ability to be successful, we have significant work ahead. Having an under secretary solely focused on innovation could not be more important than it is today.

I look forward to partnering with Congress to advance our mission, to lead in technology dominance across the DOD, and ensure the unquestioned superiority of the Joint Force while strengthening the American economy.

Thank you. And I look forward to your questions.

Senator TESTER. Ms. McQuiston, thank you for your testimony, and there will be questions.

[The statement follows:]

PREPARED STATEMENT OF MS. BARBARA MCQUISTON

Chairman Tester, Ranking Member Shelby and Members of the Subcommittee, thank you for the opportunity to testify before you today. It is an honor to be here alongside my friend and colleague Dr. Stefanie Tompkins, the Director of the Defense Advanced Research Projects Agency, DARPA. And more importantly, I am honored to represent the men and women of the Office of the Under Secretary of Defense for Research and Engineering (OUSD(R&E)). In addition to DARPA, OUSD(R&E) is home to diverse group of engineers, scientists, researchers, and staff officers who work in three separate agencies and in offices, laboratories, and universities across our nation. OUSD(R&E)'s mission is to maintain DoD's technological edge and to lead technological change and innovation throughout the DoD.

In the three years since Congress directed the creation of OUSD(R&E), and gave the office a mandate to advance technology and innovation across the Department, OUSD(R&E) has developed and begun implementing modernization roadmaps in key technology areas. OUSD(R&E) has also strengthened lab and university partnerships for basic research and worked closely with the services to improve prototyping efforts in order to bridge the "valley of death" from prototype to program of record.

Recently, Deputy Secretary Hicks assigned OUSD(R&E) the additional role of chairing a new Innovation Steering Group (ISG). This group will provide OUSD(R&E) with a mechanism for collaborating with leaders across the Department, for synchronizing innovation efforts and sharing lessons learned, and for driv-

ing initiatives to innovate at speed and scale. We convened this group for the first time last week, and the Deputy Secretary will hold her first Defense Management Action Group meeting on the subject of innovation and joint experimentation later this week. By creating the ISG, Sec. Hicks has signaled the importance of innovation and the attention it deserves. Simply put, it is a good time to be an innovator in the Department of Defense.

OUSD(R&E) consists of three core organizations and a number of subordinate agencies and activities. The office of Research and Technology (R&T) is responsible for overseeing DoD's labs, Federally Funded Research and Development Centers (FFRDCs), University Affiliated Research Centers (UARCs), academic and basic research, manufacturing institutes, and Small Business Innovation Research (SBIR). R&T's support for basic science provides the fuel that will power DoD's innovation and modernization efforts well into the future.

OUSD(R&E)'s Modernization office (MOD) connects technologies developed in laboratories with future warfighting capabilities. MOD has developed roadmaps for DoD's 11 modernization priorities—that will be addressed later in detail-to guide these key technologies from early-stage science through capability fielding.

The office of Advanced Capabilities (AC) focuses on technology transition. By conducting war games, mission engineering analysis, prototyping, and demonstrations, AC converts technologies into warfighting capabilities and gets those capabilities ready to field.

In addition to these headquarters organizations, OUSD(R&E) also houses the Missile Defense Agency (MDA), the Space Development Agency (SDA), the Defense Innovation Unit (DIU), and DARPA. DIU connects DoD with private sector innovators who use commercial technology to address some of the Department's hardest problems. MDA develops and fields advanced capabilities to defend against rogue regime missile threats. SDA is rapidly developing a new space architecture that is capable of tracking advanced missile threats. Finally, of course, I am honored to have the DARPA director speaking alongside me today.

FACILITATING TRANSITIONS

The "valley of death" is the chasm between a technology and warfighting capability. Countless technologies fail to transition into warfighting capabilities and fall victim to this valley of death. To shepherd new technologies across the valley of death instead, OUSD(R&E)'s Advanced Capabilities (AC) directorate executes nine programs that are dedicated to technology transition. By focusing on different sources of innovation, technology readiness levels (TRLs), and customer groups, these programs form a balanced portfolio that transitions capabilities to the Services, Combatant Commands, or other operational user groups, at an average rate of approximately 80%. This 80% "sweet spot" offers a responsible balance between using taxpayer dollars wisely, while also taking measured risks to maintain DoD's competitive edge.

Transition rate is an important measure of success because the Joint Staff, Services, Combatant Commands, and warfighters will not accept capabilities that do not meet their mission needs. By working closely with these partners early in the prototyping process, AC maximizes its transition rate by ensuring that partners are ready to accept and field new capabilities when prototyping completes. Beginning this year, AC added Mission Engineering to its toolbox; this process rigorously evaluates Joint Staff and Combatant Command priority missions and identifies new opportunities to transition capabilities and deliver even greater impact to the Department.

PROTOTYPING PATHWAYS TO DELIVER INNOVATION TO USERS

Results from OUSD(R&E)'s prototyping programs illustrate how, when combined with experiments and demonstrations, prototyping is an effective tool for bridging the valley of death. For example, the Quick Reaction Special Projects (QRSP) program seeks out prototyping ideas from across the innovation space, including small businesses, non-traditional performers, and academia. By discovering innovative but raw ideas and creating prototyping programs to further their development, QRSP serves as a vehicle for "technology push" and offers the warfighter capabilities that they did not realize were possible.

To ensure that DoD quickly transitions these new capabilities, QRSP awards contracts throughout the budget year of execution. For example, QRSP awarded a contract to the start-up Adronos which enabled it to compete in a "shoot off" demonstration. During this demonstration, Adranos achieved 15% better performance than other solid fuel formulations: a potential game-changer for hypersonics and long-

range precision fires. QRSP's near real-time award enabled this small business to quickly refine their novel fuel and to demonstrate its utility to DoD.

Speed is a critical enabler of technology transition, especially for emerging technologies. For this reason, the Emerging Capabilities Technology Development (ECTD) program identifies promising technologies when they first appear on the horizon. ECTD then quickly assesses the potential utility of these technologies and creates a prototype for a Service partner to rapidly evaluate. For example, in 2017, ECTD initiated a multi-Service project to prototype a cognitive software-defined radar capable of operating in congested and contested electromagnetic environments. In less than three years, the SDRadar prototype transitioned to U.S. Army and U.S. Air Force programs of record.

Finally, OUSD(R&E) maintains low-cost demonstration and experimentation venues to specifically support small business and non-traditional performers. These venues enable DoD to access cutting edge capabilities and ideas from across the innovation base. They also enable small businesses and non-traditional performers to interact with DoD users, to learn about DoD's mission, to gain experience that can be leveraged to meet future DoD needs. Two such venues, Thunderstorm and Stiletto, demonstrated technologies from 60 small businesses in FY20.

TECHNOLOGY TRANSITIONED BY OUSD(R&E) THAT IS MAKING A DIFFERENCE FOR THE WARFIGHTER

Not only do OUSD(R&E)'s prototyping programs enjoy an ~80% transition rate, they also deliver cutting-edge capabilities that make a different for the warfighter. For example:

—*Low Cost "Attritable" Strike Demonstration (LCASD) or XQ–58A Valkyrie, Joint Capability Technology Demonstration (JCTD):* Facing potential adversaries with increasingly complex air defenses, INDOPACOM issued a call for an ultra-low cost, long-range aircraft to conduct strike or reconnaissance missions. OUSD(R&E) answered the call with the LCASD JCTD. This aircraft, also known as the USAF XQ–58A Valkyrie, allows the United States to avoid placing our pilots and high value aircraft at risk during the early stages of a confrontation. The project also demonstrated agile automated manufacturing processes, gathered performance data (e.g., weight, strength, stiffness), evaluated cost model data (e.g., cost, schedule lead time), and developed in-house prototyping capability for low cost attritable aircraft technology. LCASD also proved that it is possible to rapidly manufacture a low cost, combat relevant aircraft. This accomplishment has tremendous implications for a future fleet of loss tolerant aircraft which could change the nature and conduct of warfare itself. These capabilities transitioned to the USAF Skyborg program and would not have been possible without the strong support of Congress.

—*More Situational Awareness for Industrial Control Systems (MOSAICS) Joint Capability Technology Demonstration (JCTD):* MOSAICS demonstrated a semi-autonomous solution to enhance the cyber defenses of industrial control systems associated with DoD critical infrastructure (e.g., fuel depots and electric grids). MOSAICS provides warfighters with tools to quickly identify, respond, and recover from cyber-enabled attacks on critical power, water, communication, and transportation systems. Naval Facilities Engineering Command is already planning to transition and sustain the first MOSAICS leave-behind prototype at Naval Base San Diego and is evaluating other opportunities to deploy MOSAICS capabilities at facilities in the INDOPACOM area of responsibility. Additionally, the Department is looking to use of MOSAICS to improve the cybersecurity of other critical DoD systems, including offensive cyber, long-range strike, and nuclear deterrent systems.

—*Hack-A-Sat:* Borrowing a common practice for testing system security in the commercial sector, the Hack-A-Sat project invited hackers from around the world to attempt to hack actual DoD satellites. By watching the world's best hackers at work, DoD identified new, cutting-edge hacking strategies and is developing new offensive and defensive approaches for space and cyber protection. In Q2FY21, space and cyber experts from across DoD met to apply lessons learned from Hack-A-Sat to develop new concepts for space and cyber operations. I welcome the opportunity to share additional details about this effort in an appropriate setting.

DEFENSE INNOVATION UNIT TRANSITIONS COMMERCIAL TECHNOLOGIES TO THE WARFIGHTER

In addition to prototyping to bridge the valley of death, DoD's investments must cultivate new workforce talent, attract first-time DoD vendors, and identify novel so-

lutions from across the national security innovation base: together, the Defense Innovation Unit (DIU), the National Security Innovation Network (NSIN), and National Security Innovation Capital (NSIC) partner with industry and academia to do just that. As Chinese investments aim to compete with U.S.'s technological lead in key sectors, DoD's investments can play an important role laying the foundation for a successful startup ecosystem and for ensuring national and economic security.

DIU, for example, rapidly prototypes, fields, and scales state-of-the-art commercial solutions. Leveraging the innovation, cost-savings, and economies of scale of the commercial sector, DIU has awarded contracts to 189 unique companies, of which 143 are small businesses and 61 are first-time vendors to DoD. DIU has transitioned 19 solutions to the warfighter, including small drones, automated cyber vulnerability detection and remediation, mobile endpoint security, advanced data management and analytics, air threat response, predictive mission configuration, rapid analysis of threat exposure, and space situational awareness. DIU's predictive maintenance solution scaled from one aircraft to fielding across the Air Force and Army and its small drone solutions scaled from the Army to all levels of the U.S. government. At DIU, there is also an opportunity for larger defense contractors to integrate the innovative commercial technology of smaller firms to provide ready-made solutions to the warfighter.

Like DIU, NSIN works to redefine what national security service means for academics, technologists, and entrepreneurs. NSIN runs problem-solving programs such as Hacking for Defense (H4D) to produce new concepts and capabilities for DoD end users. NSIN also works to commercialize dual-use technology developed at DoD laboratories and to support company formation and the scale-up of dual-use hardware manufacturing capabilities, including those in autonomy, communications, power, sensors, and space. NSIN partners with 66 universities in 46 states and has placed 175 people in DoD STEM positions, of which 47% were women or minorities.

MISSION ENGINEERING

Mission Engineering (ME) is an analytical approach for evaluating potential capabilities in the context of real-world missions and threats. Rigorous and data-driven, ME can help inform DoD's requirements definition and technology investment processes and can support the development of government reference architectures. In December 2020, OUSD(R&E), in collaboration with the Services, Joint Staff and the OSD engineering community, codified the ME process by releasing the first edition of the Mission Engineering Guide. This guide disseminates best practices, invokes critical thinking, and provides a consistent methodology for practitioners to use when performing ME analysis.

In FY21, OUSD(R&E)'s Mission Engineering team initiated four analyses to answer priority questions for the Department; analysis topics include: high energy lasers for base defense, position, navigation, and timing in highly contested environments, electromagnetic spectrum maneuver and mission data integration, and rapid precision strike-next. These topics were identified through a OUSD(R&E)-led workshop which included participants from the Joint Staff, Combatant Commands, and other OSD organizations. The topics were subsequently approved by the Vice Chairman of the Joint Chiefs of Staff.

To perform these and other analyses, ME requires a technical database capable of managing a large amount of data and models. OUSD(R&E)'s new Mission Engineering Digital Environment (MEDE) serves as one such database, providing analysts with a collaborative, agile, secure, interoperable, and responsive digital environment in which to conduct ME activities. OUSD(R&E) is also standing up a mission integration/mission engineering war room to facilitate collaboration across all classification levels and to meet the technical demands of multiple concurrent analyses.

To further analyze the potential mission impacts of emerging technologies, OUSD(R&E)'s Strategic Intelligence and Analysis Cell (SIAC) established an Emerging Disruptive Technology (EDT) wargame series. Wargaming is an analytical approach that enables DoD to jump-start the innovation process by grappling with the implications of emerging technologies well in advance of their maturation. EDT wargames holistically examine emerging technologies' technical capabilities and policy considerations, as well as their potential impact on operational requirements and threats. EDT wargames have examined topics such as: autonomy in undersea warfare, AI's applications to command and control, directed energy weapons, and emerging technology considerations for the Joint Warfighting Concept (JWC). Wargame outputs help inform future concept and capability development, mission engineering studies, prototyping and experimentation, threat forecasting, and S&T investments.

EDT wargames also provide a unique opportunity to integrate a diverse set of subject matter experts across program office, technology, and Service stovepipes. EDT wargames include members of the technology, operational, and intelligence communities from OSD, the Joint Staff, the Services, Combatant Commands, and intelligence agencies. This inclusive approach creates a mutually beneficial feedback loop among the organizations and individual participants. For instance, the operational community gains a better understanding of the opportunities and risks of emerging technology and the technology community gains an appreciation for future concepts and capability requirements. Both communities further benefit by learning from the intelligence community's depiction of future threats.

These feedback loops were readily apparent in 2020, during EDT Wargame 4. By assessing the 2030 technology landscape and identifying technical opportunities for the S&T community to align with the JWC, EDT 4 informed JWC's Supporting Concept capability requirements. Additionally, within OUSD(R&E), wargames are designed to inform prototyping activities, to shape modernization roadmaps, and to integrate across technology portfolios, thus enabling OUSD(R&E) to deliver the next generation of integrated capabilities to the warfighter.

TRMC DELIVERS CAPABILITY FOR TEST AND EVALUATION

The Test Resource Management Center (TRMC) ensures the readiness of the test and evaluation (T&E) infrastructure and workforce. TRMC also supports DoD modernization by forecasting future test infrastructure needs, assessing current test ranges and facilities, and developing critical test technologies and capabilities for use across the DoD T&E enterprise. TRMC, of course, also supports DoD-wide modernization by facilitating testing of key capabilities. Recent examples include:

—Improved aeroshell testing by developing an arc heater that more accurately produces hypersonic flight conditions and can evaluate thermal protection system materials;

—Upgraded a wind tunnel by developing a nozzle that provides air flow up to Mach 18 and that enables the measurement of hypersonic aerodynamics and weapon system stability;

—Enhanced the realism of nuclear survivability testing by prototyping a test capability that produces ultra-short, pulsed neutron radiation and can be used to assess the survivability of microelectronics and critical control circuits; and

—Improved 5th/6th generation aircraft testing against modern air defense systems by fielding sixteen threat-representative radar signal to assess detectability, survivability, and system performance.

In addition to strategic modernization investments, TRMC also makes foundational investments to improve test capabilities and lower the cost of testing across the Department. For instance, TRMC fielded a common range instrumentation system at eight open-air ranges. This system tracks aircraft under test with sub-meter accuracy and securely transmits highly classified flight test data down to the ground at four times the rate of previous systems.

WHERE INNOVATION RESEARCH AND TECHNOLOGY BEGINS

The Deputy Director for Research and Technology champions the Department's relationships with academia, is piloting efforts to attract a new and more diverse talent pool to the Department's science, technology, engineering, and mathematics (STEM) workforce, is promoting the use of new hiring authorities and flexibilities, and through the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) is working to bring small and innovative businesses into the Department.

GROWING THE PIPELINE OF SCIENCE, TECHNOLOGY, ENGINEERING, AND MATHEMATICS (STEM) TALENT

The Science, Mathematics, and Research for Transformation (SMART) Scholarship Program provides scholarships to U.S. citizens to pursue bachelors, masters, or doctoral degrees, and in doing so, helps build a future workforce capable of addressing the Department's most challenging problems.

Upon graduation, recipients work in a civilian position in a lab or agency of the Army, Navy, Air Force, or other DoD entity and have a one-year service requirement for each tuition year. In 2019, DoD targeted scholars with academic backgrounds that aligned with DoD's modernization priorities, including: quantum science, microelectronics, biotechnology, and artificial intelligence. Continuing to recruit stellar candidates into the SMART program will enable DoD to build a workforce that is capable of addressing even the most challenging science and technology problems in the future.

OUR COMMITMENT TO DIVERSITY

To attract and advance an inclusive DoD STEM workforce, the Department's STEM Education and Outreach efforts are working to increase women's and other underrepresented groups' involvement. For example, OUSD(R&E) conducts SMART Scholarship program outreach at Historically Black Colleges and Universities and Minority-Serving Institutions (HBCU/MI). DoD's long-standing partnership with HBCUs/MIs not only contributes to a diverse STEM workforce, it also focuses research grants on core DoD modernization priorities. Furthermore, although the DoD's HBCU/MI program research focuses specifically on defense, program investments also contribute to commercial innovation.

The HBCU/MI Program also manages nine centers of excellence that provide leadership, research, and education in DoD priority areas. The newest centers focus on quantum sensing, artificial intelligence/machine learning, networks, aerospace education, research, and innovation. The program is also working to establish to new centers focused on biotechnology and materials science. Finally, two other centers of excellence have a STEM workforce focus, and are cultivating a cohort of students through an education program that is coupled with exposure to the DoD's research and development enterprise. Many of these students also participate in DoD internships; after completing internships, 57 STEM scholars who also participated in the DoD HBCU/MI Program have accepted job placements with defense laboratories since FY 2018.

LEVERAGING INTERNATIONAL TALENT

To stay ahead of our competitors, both economically and militarily, the U.S. must continue developing and attracting world-class scientists and engineers. The Department employs more than 130,000 scientists and engineers, and nearly half of this number work in one of the Department's laboratories or engineering centers. Despite challenges in recruiting and retaining technical talent, the Department maintains an exceptional workforce. Many of the U.S.'s top researchers and entrepreneurs have come here from other countries. To take advantage of this fact, in just the last year, OUSD(R&E) re-invigorated the Department's J–1 Visa waiver program. This effort will reduce barriers for foreign nationals who want to stay in the country to work in STEM fields.

Today's U.S. universities welcome a high percentage of international students, scientists, professors, and industry collaborators, and our adversaries compete with the U.S. to recruit from this same talent pool. Immigrants have been awarded 38% of the Nobel Prizes won by Americans in Chemistry, Medicine, and Physics since 2000 and immigrants or their children founded 45% of the 2019 Fortune 500 companies. We want these individuals to come here, stay here, and choose to work with us no matter where they were born. It is our strategic imperative to continue recruiting the best, highly-skilled individuals-regardless of national origin-to work within the U.S. research enterprise.

UTILIZING HIRING FLEXIBILITIES

The Department continues to make extensive use of recruitment and retention authorities to enhance its science and technology workforce. These authorities give Service laboratories the ability to conduct direct hiring in particular fields, such as cybersecurity, to support continuing education, provide recruitment bonuses, and reward employees with performance-based pay.

These tools allow DoD laboratories to recruit and retain top S&T talent and remain competitive with the private sector. For instance, the Air Force Research Laboratory (AFRL) has used the Enhanced Pay Authority to hire subject matter experts in the areas of autonomous systems, data analytics, and communications and networking, which directly enhances their ability to support the Department's modernization priorities.

THE ROLE OF SMALL BUSINESS

The Department invests nearly $2 billion annually in innovative small businesses, entrepreneurs, and academic research institutions through the Small Business Innovation Research (SBIR)/Small Business Technology Transfer (STTR) programs. These programs provide the DoD access to the small business community, reaching experts and academics that may not otherwise be engaged.

Small businesses that begin working with DoD through the SBIR/STTR programs have the option of partnering with existing contractors or larger businesses that may already be working on Programs of Record or fielded services. For many small businesses this is a "foot in the door" providing experience working with the DoD

and providing DoD with access to new perspective and talent from the small business community. Moreover, SBIR/STTR projects are often dual-use, and are both transitioned to the military and commercialized for private-sector benefit. The Department facilitates both military transition and private sector commercialization opportunities through Component SBIR/STTR Commercialization Readiness Programs (CRP) and the OSD Transitions SBIR/STTR Technologies (OTST) Program. The Department also held its first Virtual Symposium on transition in October 2020 with over 1,000 participants from small businesses, primes, and academia.

DoD has focused the SBIR and STTR investment programs on the Department's modernization priorities. Additionally, DoD has streamlined and modernized the SBIR and STTR proposal submission process, with the goal of making these programs more accessible to small, domestic firms.

In order to promote small business within the defense contracting space, the DoD facilitates licensing opportunities through our national partnership intermediary, TechLink. Partnership with TechLink offers licensing support to small businesses working with the DoD, which is mutually beneficial, delivering value to the small business and enabling further innovation.

Additionally, the Department encourages larger defense contractors to work with small businesses, including SBIR/STTR performers, through specific subcontracting requirements and through the Mentor Protégé program managed by the Office of Small Business Programs within the Office of the Under Secretary of Defense for Acquisition and Sustainment. These mechanisms further assist small businesses to contribute to Defense innovation, while also making it easier to do business with the DoD.

HOW SMALL BUSINESS INNOVATION IN DOD HELPS AMERICA BROADLY

DoD reaps tremendous benefits from partnering with small businesses. A recent study of the SBIR/STTR programs found the Department achieved a 22-to-1 return on investment in small business research and development over the past 23 years, resulting in $347 billion in total economic output. An economic impact study conducted in 2018 on the DoD license agreements active during the 2000–2017 period revealed $27 billion in sales of new products and services, including at least $5 billion in confirmed sales to the U.S. military. Overall, these agreements generated over $58 billion in total economic impact and created approximately 215,000 jobs. In this study, small businesses accounted for approximately 80% of the licenses.

THE DEFENSE MANUFACTURING BASE

Manufacturing is critical to the advancement of our technology modernization objectives. The DoD Manufacturing Technology program (ManTech) executes a portfolio of project investments across OSD, the Services, and Agencies, focusing on advanced manufacturing technologies. The ManTech program also serves as a lead Federal strategic investment partner to 9 of the 16 Manufacturing USA innovation institutes (MIIs).

These MIIs promote domain-focused manufacturing ecosystems in areas of value to the Department and identify emerging areas of importance to the U.S. manufacturing base. The MIIs employ pre-competitive technology advancement and investment, and facilitate community building and workforce development. They bring together industry, academia, and federal partners to increase U.S. manufacturing competitiveness and promote a robust and sustainable national manufacturing R&D infrastructure.

For example, the Manufacturing times Digital (MxD) Institute recently welcomed 5G on its Future Factory Floor to serve as a testbed for demonstrating the opportunities 5G, artificial intelligence, and machine learning bring to manufacturing. The ManTech team has also begun to accelerate advanced manufacturing technologies through public-private partnerships in cybersecurity, photonics, and regenerative medicine.

Solar power and our most advanced medical diagnostic machines both depend on advanced photonics. The American Institute for Manufacturing Integrated Photonics (AIM Photonics) is an engineering technology consortium that has established a U.S.-based Photonic Integrated Chip (PIC) manufacturing ecosystem. This ecosystem is leading efforts in the prototyping, validation, and final packaging of advanced node microelectronics and photonic chip fabrication, and the development of test, assembly, and packaging facilities.

Last year the Department established its ninth DoD-lead Manufacturing Innovation Institute—BIOMADE, to specifically focus on bio-industrial manufacturing. This institute leverages emerging biotechnologies, including modern engineering biology techniques, to foster domestic leadership in bio-manufacturing. BIOMADE is

already building partnerships across the U.S. bio-economy and strengthening linkages between defense needs and industry and academic partners.

Hypersonic weapons depend on the manufacturability of carbon-carbon materials. Working to address this need, ManTech is sponsoring the manufacture of carbon-carbon composite for the Hypersonics Applications (MOC3HA) initiative. This effort works directly with domestic manufacturers of carbon-carbon material to streamline processes and improve quality and reliability volume and size, reduce cost and cycle time, and increase yield.

The department has convened a DoD-wide Manufacturing Council to coordinate activities addressing defense-wide challenges as well as human capital investments and strategies, and to serve as a touchpoint for industry. Through this Council, we align the funds in the ManTech program, Industrial Base Analysis and Sustainment effort, and Defense Production Act Title III authorities to achieve our modernization goals and to maintain our technical advantage.

SUPPORTING DOD'S MIIS RESPONSE TO THE COVID–19 PANDEMIC

America Makes, the DoD-sponsored institute for additive manufacturing, rapidly partnered with the Food and Drug Administration (FDA), HHS/Assistant Secretary for Preparedness and Response (ASPR), National Institutes of Health (NIH), and Veterans Affairs (VA) to efficiently and safely match health care provider needs for PPE. This project also developed a rapid method for design submission and approval of 3D PPE designs under DoD funding.

As of February 25, 2021, more than 624 published designs were available on the Exchange, with 34 designs optimized for clinical use and 28 designs optimized for community use. These designs have been downloaded over 200,000 times with more than 2.5 million views. Through the effort, America Makes assisted front line workers in obtaining hundreds of thousands of pieces of critical PPE supplies from qualified manufacturing across the U.S.

The NextFlex Manufacturing Innovation Institute facilitated a project that uses novel RNA sequencing technology to prove the environmental contamination and transmission pathway, then refined and expanded production capacity of antimicrobial mats called "clean surfaces" to address surface contact infections. Virus and bacteria surface contact infections are frequent, and pathogens often remain viable and contagious between surface cleanings even if proper episodic procedures are followed.

For this novel "clean surface" technology, any time microbes contact the mat surface, an embedded circuit board sends a micro-electric impulse along printed conductive traces to that location to activate antimicrobial silver and copper ions that quickly eradicate the contaminants. The flexibility of these mats allows them to be placed around the side rails of hospital beds, on tables, or doorknobs. The application of this innovation to public, medical and retail infrastructure in the long-term could impact how future viral outbreaks are controlled, especially during flu seasons. The mats went through validation testing throughout the University of Pittsburgh Medical Center hospital system and are now being installed in six hospital ICUs for a six-month experiment to measure pre- and post-infection rates.

The Advanced Functional Fabrics of America (AFFOA) is a DoD-sponsored advanced fabrics institute and was selected to participate on the Commonwealth of Massachusetts' Manufacturing Emergency Response Team. Alongside the Massachusetts Technology Collaborative, AFFOA helped administer $5.6 million in funds for PPE through the Massachusetts MII program for domestic manufacturers pivoting to manufacture PPE, identified opportunities to rapidly optimize the PPE supply chain, matched PPE manufacturers with producers of raw materials, and connected hospitals to manufacturers to quickly produce needed products. AFFOA also built a distributed PPE material-testing network to assist hospitals, state emergency management agencies, first responder organizations, and domestic manufacturers to test their materials and PPE products and ensure product performance and regulatory compliance.

STRENGTHENING OUR DEFENSE RESEARCH BASE

Scientific discoveries occurring at universities and laboratories supported by the DoD, have led to dramatic commercial and national security advances and have significantly improved citizens' lives around the world. DoD's relationship with academia is an incredibly valuable force multiplier for the basic research enterprise.

In addition to our Defense Laboratories, the Department's FFRDCs and UARCs are a critical element of our innovation base, providing the independent and objective scientific and technical expertise that the Department relies on to create tech-

nical superiority. Last year, we undertook a concerted effort to ensure the Department employs our FFRDCs for maximum strategic impact.

In FY19, the FFRDCs and UARCs made numerous contributions to enhance the capabilities of the Joint Force. For example, the Aerospace Corporation was an integral part of the Government and contractor team that successfully launched a GPS III on a Falcon 9 rocket. This was the first flight of a competitively awarded National Security Space Launch mission in nearly 20 years. In another instance, the Johns Hopkins Applied Physics Laboratory developed a technically rigorous "space game" that enabled participants to grapple with realistic and technically informed timelines, authorities, questions, and rules of engagement, and the operational implications of pursuing different space architectures. Playing out these scenarios has informed the department's investment decisions.

INTERNATIONAL PARTNERSHIPS

Our Allies are essential to our national security. This is true in research as it is in warfighting. We continue to develop our international partnerships through the SMART program. Two examples from the SMART program to highlight are the Alan Turing Institute in the U.K., where SMART scholars can perform research on artificial intelligence and machine learning, and the von Karman Institute for Fluid Dynamics in Belgium, where SMART scholars can perform research on hypersonics. Through these efforts, scholars work with their peers overseas improving our S&T community and contributing to the Department's international partnerships.

TECHNOLOGY PROTECTION

Our military's technological edge is at risk. Competitor nations are acquiring intellectual property and sensitive technologies from our academic research system and industry through illicit and legal means. The department is taking a multipronged approach to address this issue. We are applying protections for critical technologies and programs that prevent technologies from falling into the wrong hands. We are establishing procedures to reinforce the integrity of our research enterprise. We are also engaging the broader S&T community and our stakeholders to provide improved threat awareness, inform necessary controls, and develop best practices that can be institutionalized across the DoD S&T enterprise.

We continue to look for new methods to secure our technology. Technology Area Protections Plans (TAPPS) are new initiatives we are using to provide a common understanding of what needs to be protected and a strategy to establish protections. TAPPs will help S&T organizations get information regarding emerging and disruptive research that can be used to apply safeguards through Program Plans. The TAPPs in development align with the 2019 DoD list of critical programs and technologies mandated by Section 1049 of the FY2019 NDAA.

We have also taken other steps to protect open research at U.S. institutions. R&E is currently working with other federal research funding agencies to develop common standards for identifying and adjudicating conflicts of interest and conflicts of commitment. We are fully engaged with the White House Office of Science and Technology Policy to develop Federal guidance for Research Security and Integrity.

In March 2019, we issued instructions to our partners in academia, requiring that key research personnel funded by DoD grants, cooperative agreements, Technology Investment Agreements, and other non-procurement transactions disclose all current and pending projects and funding sources. We are also revising research grant and cooperative agreement procedures to exclude research funding for individuals posing an unacceptable risk to national security or participating in foreign talent recruitment programs. Moreover, DoD encourages academic institutions, associations, and councils to develop training modules for faculty to clearly explain the landscape of threats to research integrity.

Technology protection requires a nuanced and multifaceted approach as well as partnerships with other government agencies, industry, academia, and allies. An uncoordinated, broad-brush approach to technology protection can result in damaging consequences that inhibit leading-edge research. At the same time as we work to protect our technological edge, we recognize that the free exchange of ideas and collaboration are critical to our continued success. We must preserve the long-standing norms that have benefited our research institutions while at the same time punishing bad actors who break the law. While we must guard against espionage and the theft of intellectual property, we must also nurture an open, pioneering and collaborative culture that has historically served our country so well.

CREATING AND PROMOTING NEW TECHNOLOGIES

The office of the Director of Defense Research and Engineering for Modernization develops and coordinates Department-wide science and technology strategies to guide and drive technology development and inform requirements. By developing S&T roadmaps, we prioritize resourcing, support future technology insertion, and provide opportunities for investments to accelerate development efforts. Our current efforts are focused on 11 modernization areas; 5G, Hypersonics, Directed Energy, AI, Biotechnology, Microelectronics, Cyber, Quantum Science, Autonomous Systems, Fully Networked Command and Control, and Space.

Microelectronics

Microelectronics is a critical focus area for DoD Modernization. Advanced capability microelectronics technology development directly influences success in fielding disruptive technologies, including Artificial Intelligence, Hypersonics, and 5G. The US is struggling to maintain global competitiveness in leading edge fabrication and design innovation, despite supporting a diverse infrastructure of research, design, intellectual property (IP) rights, and physical plants that should enable the US to be an attractive market for the semiconductor industry. Additionally, aggressive investments and actions by peer competitor nations threaten U.S. leadership. Russia and China have publicly stated that advanced microelectronics and AI are the keys to economic and military dominance. Nearly 90 percent of the world's semiconductor foundry market share belongs to companies with foundries in Taiwan, South Korea and China. This imbalance is prompting calls to boost domestic capacity.

R&E's Trusted and Assured Microelectronics (T&AM) Program is executing the development of key technologies in accordance with the DoD Microelectronics roadmap. The broad goals of the T&AM program are to secure U.S. microelectronics interests, reverse the erosion of domestic innovation and supply, and establish a strong leadership foundation for the next-generation of microelectronics technology for DoD applications. We are involved in three lines of effort to reach these goals:

1. Assurance of the integrity of microelectronic products as they move through the supply chain through the development and application of enhanced assurance technologies, services, and standards.
2. Availability of critical and common IP, manufacturing capabilities, and assurance tools and services required for DoD research, development and acquisition programs.
3. Access to design modules, design capabilities, manufacturing, and verification and validation services at commercial sources with lowered barriers and integrity/confidentiality protection measures.

We plan to continue investing in advanced capability microelectronics, ensuring access to State of the Art microelectronics, advanced packaging and test, and to radiation hardened microelectronics. We are also moving forward with the establishment of the Joint Federated Assurance Center, and continuing to investment in the DARPA led Electronics Resurgence Initiative (ERI). ERI is intended to ensure U.S. microelectronics technology leadership well into the 21st century. ERI will pursue electronics performance advancements by leveraging circuit specialization, to include materials, architectures and designs.

ARTIFICIAL INTELLIGENCE

We are in a global arms race in artificial intelligence technology and applications, most notably with China, who has set a goal to lead in AI technology by 2030. To maintain US dominance in AI, we will:

1. Continue to invest in cutting-edge AI research through organizations such as DARPA and Office of Naval Research (ONR).
2. Democratize DoD AI innovation by developing modern data and software development processes providing end-users and warfighters the ability to engage with AI development directly.
3. Accelerate AI adoption by supporting a rapid development pipeline, from research to our engineering centers to the service software factories and program offices.

This three-prong approach will lead to: trusted AI capability that has high utility to the warfighter, decreased development timelines, lowered cost-structures and reduced maintenance; increased understanding and availability of DoD data which is so vital to AI development; and improved talent development and retention within the civilian and service member community. Although this revolution is in its early phase, the capability is currently being tested in such areas as predictive maintenance, business operations, and automated target recognition. More generally, AI

will enable a myriad of capabilities across the force, including intelligence fusion and analysis, planning and prediction, and longer-term autonomy.

Just as the second wave of AI research performed within the Department 20 years ago led to the explosion of commercial activity in the US today, R&E is heavily involved in a third wave of advanced AI techniques and capability that will further strengthen the American AI ecosystem and have future commercial impacts.

CYBER

Our adversaries are engaged in wide-ranging and highly impactful malicious activities in cyberspace, often with near-impunity. Fortunately, through the implementation of the 2018 DoD Cyber Strategy, which embraces a defend-forward and persistent engagement approach, US Cyber Command and the Service Cyber Components are now blunting and disrupting many of our adversaries' malicious cyberspace activities. Through this approach, and by leveraging new capabilities made possible through significant and long-term DoD S&T investments, our cyber forces are now exacting far greater costs on our adversaries.

To build on this momentum and ensure increasing dominance, our cyber strategy calls for increased investments to accelerate the development and rapid transition of technologies that provide the basis for 1) vastly enhanced resilience of DoD systems and critical infrastructure 2) substantially increased capacity and unrivaled capabilities for the conduct of cyber and cyber-enabled operations, 3) overmatching skills and expertise within the Cyber Mission Forces, and the Cybersecurity and Cyber S&T workforces.

Further, thanks to Congress' support of FY20 and FY21 appropriations totaling $20M, OUSD(R&E) is awarding the first three academic Cyber Institute consortiums in April 2021. Known as VICEROY (Virtual Institutes for Cyber and Electromagnetic Research and Employ), they will prepare future ROTC and DoD-minded civilians for challenging cyber and electromagnetic spectrum operations and research careers through experiential learning. These increased investments in both technology and human capital will compound the dividends of the now decade-long increased focus, by DARPA and the Services, on the development of innovative and increasingly sophisticated cyber technologies.

5G

Technology to secure 5G communications is paramount to leveraging 5G for operations and communications superiority. As an investor in and significant consumer of technological innovation, the Department drives a cycle that parallels civilian industry and leads to new capabilities and services that would otherwise not be available. The technologies being developed and tested in the 5G Initiative will drive U.S. technology and innovation. Further, the dual-use applications being developed will help U.S. industry get 5G-enabled products to the commercial market more quickly while also providing DoD with new operational capabilities.

Security is often "bolted on" after a system has been developed. 5G networks, prototypes, and operating procedures are being developed now, and the 5G Initiative is actively working with industry to address security early by engaging both large integrators and non-traditional performers in experiments at over a dozen DoD facilities around the country. Examples include new 5G techniques for device authentication, using network slices (virtual networks on top of the underlying network) for threat detection and protection, and using multiple network paths for added resilience. We are working with industry and the standards community to build security into the design from the start, so security is viewed as a key metric, comparable to factors like network speed and latency.

Our 5G Initiative emphasizes Zero Trust principles, that is, moving away from defenses based on perimeters to defense in depth. Perimeter-based defenses are ineffective in dynamic environments that include multiple mobile devices, potentially untrusted supply chain components, and massive scale—all of which are anticipated under 5G. A perimeter defense is like a castle and moat defense; one builds a moat and wall around the protected center to keep the threat outside the castle and moat. In dynamic 5G environments, there is no castle. Instead, we need to think in terms of an in-depth defense strategy that assumes an adversary may be anywhere in the 5G environment. Continuous monitoring and rapid detection of unintentional faults and malicious attacks allow us to adapt in real time.

The 5G Initiative is developing multiple 5G testbeds across the country to demonstrate the efficiency and capability that 5G will enable for the Department of Defense. The testbeds provide the Services the ability to develop and test novel capabilities in at-scale environments that would otherwise not exist. The testbeds represent 10 different projects spanning 14 military locations and representing over seven tactical and operational mission areas/use cases. At Hill AFB, the 5G Initia-

tive develops technology to enable 5G networks to share spectrum with airborne radars dynamically. At Naval Base Coronado and Marine Corps Logistics Base Albany, the 5G Initiative is developing smart warehouse technology enabled by 5G. The technology will enable more efficient, accurate, and timely delivery of warfighting material. At Joint Base Lewis-McChord, the 5G Initiative develops Augmented Reality/Virtual Reality for the training environment.

Finally, ongoing dialogues with Service Programs of Record (PORs) ensure that the research projects address service requirements and that PORs are making plans to transition and incorporate successful 5G developments.

Autonomous Systems

DARPA's "Grand Challenges" on autonomous vehicles served as the primary catalyst for significant interest—and investment—by academia, industry, and government in autonomous systems. Building on this legacy, DoD application of intelligent, autonomous behaviors to robotic and unmanned systems (across all warfighting domains) is poised to allow humans and machines to team and achieve an overwhelming warfighting advantage not possible by humans or machines acting alone.

These behaviors increase efficiency by reducing the physical and/or cognitive loads on the warfighter; reduce risk to warfighters by reducing manned operation in harsh and unpredictable environments; and provide the potential to generate cost-effective combat mass. Moving beyond today's current limited fielding of intelligent autonomous systems that primarily support intelligence, surveillance, and reconnaissance activities with platform-level autonomous navigation, future capabilities will be applied across the spectrum of warfighting functions.

In the near-to-mid-term, autonomy efforts within research and engineering will result in advances in a number of areas, including; responsive fires support based for both manned and unmanned sensor and weapon systems; effective, resilient resupply using autonomous systems from point of manufacture to delivery; and joint all-domain and control enabled by autonomous systems increasing reconnaissance and surveillance ability.

To speed the development of these effective, appropriate, and safe intelligent autonomous systems, the DoD will continue to develop the digital engineering infrastructure necessary to design, fabricate, and test these systems throughout the entire Robotics and Autonomous System lifecycle. Successful fielding of these systems will leverage ongoing efforts to develop and implement a comprehensive Joint all domain command and control system as well as efforts to develop a secure cloud environment including a cloud-to-edge strategy suitable for contested environments. In concert, we must conduct virtual and live experimentation to fully explore future operational concepts as well as continue to develop sound, thoughtful, and ethical principles for the employment of Robotics and Autonomous Systems.

BIOTECHNOLOGY

Biotechnology will fundamentally change the future battlefield, and US adversaries (most notably China) are aggressively pursuing related capabilities. Furthermore, China has signaled willingness to use this and other emerging technologies against their opposition without respect for protocols, conventions, or human rights. Biotechnologies hold potential to broadly impact defense capabilities; however, until recently, DoD investments have almost exclusively focused on medicine and chembio defense missions.

A key application of biotechnology to national security is the ability of bioindustrial manufacturing to generate novel, domestic, safe, and sustainable sources of critical supply chain components. For example, a project executed by ONR and NAVAIR China Lake demonstrated the use of engineered bacteria to produce linalool, which can be efficiently converted to jet fuel, diesel, gasoline, and high density missile fuels. Other DoD efforts, such as DARPA's Living Foundries program, have illuminated the potential for more than 1,000 DoD-relevant molecules to be produced using biology.

The Department is prioritizing partnerships with Industry, to include BIOMADE—the newly awarded Bioindustrial Manufacturing Innovation Institute (MII)—and in collaboration with the Services, is focusing biotechnology modernization on: (1) building a common foundation of physical and digital infrastructure to create a rapid prototyping pipeline, (2) identifying and prioritizing use cases for prototyping and demonstration, and (3) enhancing workforce development opportunities. Investing in a pipeline for advanced development of bioindustrially-sourced products will not only provide critical materials and capabilities for our warfighters and maintain our competitive advantage in the field, a robust industrial base will also ensure that the future global bioeconomy is made in America.

DIRECTED ENERGY

Directed Energy Weapons can provide US forces with a high rate of fire weapon with a reduced logistical burden. This capability will be especially important as potential adversaries continue to develop advanced missile capabilities. We are working with the Services to accelerate operational weapon system development and operational experimentation, to build the industrial base, to develop the needed science and technology, and to carry out the capability development and demonstrations leading into programs of record.

Through our Laser Scaling Program, we are using industry to build 300 kW high-energy lasers by the end of 2022, and then we are increasing power to 500 kW by the end of 2025, and to 1000 kW by the end of 2028, all while reducing the size, weight, power, and thermal needs of these systems. Through our Rapid Prototyping Fund, the Navy will operationally test new laser and high-power microwave weapon prototypes at sea in 2020 and beyond. Further, we have partnered with the Special Operations Command to accelerate programs for airborne and land-based laser strike weapons. We have partnered with the Army Futures Command and the Navy to accelerate land- and sea-based laser and high-power microwave weapons for integrated air-and-missile defense, with initial demonstrations in 2022, key decisions in 2023, and initial capability in 2025.

In anticipation of new and more lethal directed energy weapons transitioning to programs of record, we are upgrading our test and evaluation capabilities with new infrastructure at the test ranges. Along with all this effort there is a tightly coupled science and technology effort aimed at lethality, beam control, propagation, power, and thermal management. Multi-domain mission analysis is being carried out to expand the range of missions and to enable directed energy weapons integration into the Joint Force.

FULLY NETWORKED COMMAND, CONTROL & COMMUNICATIONS (FNC3)

To improve command, control and communications (C3) the department is focused on providing the capability to evolve rapidly and independently between systems, equipment and users. This effort involves integrating stove-piped C3 systems into a layered architecture. The FNC3 effort is closely tied to Joint All Domain Command and Control (JADC2) and together these efforts are synchronizing investments across the DoD to ensure that the Joint Force's C3 are interoperable, resilient and capable.

By breaking-up the current stovepipes, we can increase resilience and improve Quality of Service (QoS—data rate and latency).

We are also making rapid developments in software defined radios and investing digital active electronically scanned antennas and optical communications systems. This will strengthen the resilience of individual links, grow capacity, improve interoperability and enable rapid fielding of better waveforms and algorithms. DoD is already transitioning and taking advantage of these new capabilities, such as the upgrades to the Multifunctional Information Distribution System (MIDS), which includes Link-16, and the Warrior Robust Enhanced Network (WREN).

We are leveraging recent concepts in Software Defined Networking (SDN) such as network slicing, to manage all the available diversity and deliver the much needed resilience with the necessary Quality of Service. Our investments are targeted at optimizing SDN concepts to our DoD tactical and strategic networks, as they are different from the commercial networks where SDN has been implemented to date. The US Navy's Tactical Data Dissemination Initiative (TDDi) is an early transition of these SDN technologies. To improve interoperability between applications in the short term, machine-to-machine interoperability technologies (e.g. efficient translators) such as DARPA's STITCHES program are ready for transition.

In the medium and long-term the Department (led by the DoD CIO's Office) is moving towards a federated data-centric architecture to reduce the overhead associated with current approaches to interoperability. In support, we are investing in a data-centric approach to C2 messaging (known as Universal Command and Control—UC2) that takes advantage of a recent encoding innovation, variable format binary (e.g. ProtoBuf and EXI), to produce a C2 messaging standard that is simultaneously efficient, evolvable and broadly applicable. An initial demonstration of the data-centric C2 techniques applied to the Counter Unmanned Ariel Systems mission is planned for the end of this year. Improving our C2 applications ability to better infer relevant information from the available data and provide decision support is also key to better C2 with investments coordinated across multiple modernization portfolios including AI, Autonomy and FNC3.

HYPERSONICS

Hypersonic systems take advantage of speed, maneuverability and sustained flight in the altitude gap between air defenses and ballistic missile defenses to provide transformational capability for survivable, long-range, lethal, time-critical strike of heavily defended and high value targets.

Hypersonic systems are enabled by innovations in highly integrated aerodynamic configurations, high temperature materials and structures, high speed propulsion, and advanced guidance, navigation and control. Over the past decade, focused research, development, test and evaluation has created the opportunity to rapidly transition developmental system concepts to weapon system prototypes and to operational weapon systems. We are working in close coordination with the Services to accelerate development and fielding of multiple air, land and sea launched conventional hypersonic strike weapons to defeat targets of critical importance.

Our potential adversaries are rapidly evolving high-end offensive and defensive systems creating highly contested anti-access/area denial (A2/AD) environments that challenge our tactical battlefield dominance and necessitate the development of hypersonic strike capabilities.

Additionally, our potential adversaries are aggressively pursuing, and now fielding a variety of hypersonic systems. This compresses the timescale on the tactical battlefield, creating asymmetry, which we are working to address. We will continue to implement our integrated strategy to enable fielding of operational prototypes in quantity from land, sea and air by the mid-2020s.

We are also working with the Missile Defense Agency to accelerate a comprehensive layered defeat capability against adversary tactical hypersonic weapons including kinetic defense in the terminal and glide phases of flight, as well as left-of-launch strike of missile launch complexes. The DoD hypersonics capability fielding strategy is being implemented through a highly coordinated set of programs across the services and agencies, to include a joint service memorandum of agreement and middle tier acquisition programs to effectively accelerate capability to the warfighter. Critical investments in our industrial base, our workforce, applied technology, and test infrastructure are being made to enable this acceleration and to pave the way for technical superiority for decades to come.

The Joint Hypersonics Transition Office (JHTO), which resides in our Advanced Capabilities directorate, works in close coordination with our Principal Director for Hypersonics to accelerate the development and transition of hypersonic technology to the warfighter. As the engineering and execution arm for hypersonics in the Office of the Secretary of Defense, the JHTO works closely with the Principal Director for Hypersonics to identify and address critical science and technology and workforce gaps and opportunities to ensure the success of the Hypersonics Strategy. In a resource-constrained environment with an adversary operating with more resources and faster development timelines, the JHTO addresses the need to accelerate and more efficiently develop hypersonic technologies by tying S&T investments directly to identified military needs, providing mechanisms for closer collaboration and coordination across the government, and identifying opportunities to tap into non-traditional performers such as universities and foreign allies.

The JHTO has five lines of effort aimed at increasing the speed of innovation in the U.S. and allied hypersonics enterprise:

1. the JHTO develops capability-based S&T roadmaps covering basic and applied research to guide the hypersonics S&T enterprise and funded $48M in FY2020 in 28 projects to accelerate technologies that address the most critical S&T gaps.

2. the JHTO is sponsoring an effort with Boeing and Aerojet and the AFRL to mature a propulsion design to enable a hypersonic cruise missile option for aircraft carrier-based F/A–18s and a joint USAF/USN missile.

3. the JHTO in November 2020 stood up a university consortium of applied hypersonics at the Texas A&M Engineering Experiment Station (TEES) that enables nearly 100 universities to work on applied hypersonics research, provide expertise to the government, and to address workforce gaps. The JHTO is funding $20 million a year in university research through the consortium and has made this research ecosystem available to the rest of the government to access applied hypersonics research.

4. As the lead for allied engagements in hypersonics, the JHTO is the co-chair of the Australia-US Hypersonics Working Group (HWG) formed in August 2020 to develop a bi-lateral strategy and coordinate S&T and activities in hypersonics.

5. the JHTO in October 2020 stood up the JHTO Systems Engineering Field Activity at NSWC Crane in Indiana to provide the systems engineering rigor

to JHTO-funded S&T efforts to ensure that they can transition into our programs.

QUANTUM SCIENCE

Successes in the area of quantum science research at DoD demonstrates how early-stage research can have a multiplier effect in other areas important to national security. A clear line can be drawn to the 20+ years of basic research funding within the DoD, and the major successes we are now seeing in U.S. commercial industry related to atomic clocks, quantum computing, the growing importance of quantum sensors, and quantum networks. These quantum technologies have significant economic and national security impact, made possible as a result of long-term, dedicated basic research funding.

Recent increases in federal funding through the National Quantum Initiative Act have led to increased levels of coordination with government partners. Increased commercial investments in quantum computing and quantum sensors are leading to new opportunities for DoD to engage and look towards transitioning this technology for military advantage. DoD is focused on the long-term opportunities of this technology for both military and civil applications.

Advances in quantum science are only beginning, and there is much more potential to discover through research. As quantum technologies develop, their importance to our economy and to national defense are likely to increase.

SPACE

The US cannot cede its dominance in space. Space related work will enable the US economy, diplomacy, and the military.

The dominance of the US in space is being challenged. Potential adversaries are showing their ability to rapidly deploy space capabilities, they are extending their reach to the Moon, the area between the Moon and the Earth, and they are innovating with technologies that challenge norms of behavior and provide asymmetric advantages threatening both terrestrial and space capabilities.

We are exploring numerous game-changing technologies with the labs and international partners such as advanced quantum encryption, artificial intelligence and smaller satellites that provide more capabilities, and austere on-demand responsive launch systems. Most notably, we have just initiated a new space research consortium program to mine the best and brightest researchers from universities and the tech base to focus on the hardest of space challenges identified collaboratively through a Board of Directors consisting of R&E, US Space Force, DARPA, DIU, Department of Energy, NASA and others. In addition to speeding the deployment of new space technologies through efforts like SpaceWerx and the space software factories, we are exploring cis lunar architectures and technologies such as space domain awareness, rapid maneuver and long-duration station keeping, through collaborative efforts in nuclear power and propulsion with the Department of Energy.

MISSILE DEFENSE AND SPACE DEVELOPMENT AGENCIES

The Missile Defense Agency (MDA), the Defense Innovation Unit (DIU), and the Space Development Agency (SDA) fall under the R&E umbrella. MDA and SDA are working on programs providing our nation with defense against some of the most advanced threats in the world. DIU plays an essential role in providing an entry point for innovators in the private sector to engage with needs of the DoD.

MISSILE DEFENSE AGENCY

The Missile Defense Agency (MDA) is developing capability and technologies that address the evolving missile threat. MDA will develop a Next Generation Interceptor (NGI), which improves homeland missile-defense performance and survivability against the assessed rogue nation threats as part of the Missile Defense System (MDS). In FY 2021, MDA will award the design and development activities for two competitive NGI development contracts. The initiation of the NGI program and the continued Ground-based Midcourse Defense Service Life Extension Program will extend the existing Fort Greely, Alaska, and Vandenberg Air Force Base, California, capability to defend the homeland from ballistic missiles beyond 2030.

The Department is investing in technologies and studying capabilities to defeat regional offensive hypersonic weapons, the first element of which is to detect and track incoming missile threats. MDA delivered a capability for USINDOPACOM for real-time sensing and display of hypersonic and maneuvering vehicle tracks. This capability is operational now in support of the Missile Warning and Missile Defense missions. In collaboration with industry partners, US Space Force, USNORTHCOM,

USSTRATCOM, USSPACECOM, and the Space Development Agency, MDA is pursuing a Hypersonic and Ballistic Tracking Space Sensor (HBTSS). Once deployed, HBTSS will become a key element of the MDS in hypersonic defense by providing a persistent, layered capability to detect and track dim boosting ballistic missiles, hypersonic glide vehicles, and raids in all phases of flight. MDA awarded two agreements earlier this year to industry to build an on-orbit prototype-demonstration space vehicle for a planned launch in 2023.

With the achievement of Initial Fielding in fourth quarter FY 2021 and operational acceptance in first quarter FY 2023, MDA will add the Long Range Discrimination Radar in Alaska into the MDS architecture to provide a persistent capability to defend the United States homeland against IRBMs and ICBMs. This past year the Department demonstrated the ability of the Patriot missile defense system to intercept a short-range ballistic missile target using THAAD/AN/TPY–2 track and discrimination data. MDA also is continuing to mature an integrated air and missile defense capability for regional defense.

MDA, in cooperation with the U.S. Navy, demonstrated early capability against maneuvering threats during flight-testing of the Standard Missile (SM)-6 Sea-Based Terminal (SBT) defense, and it will further demonstrate this capability against an advanced maneuvering threat-representative target later this year. We will continue to advance our SBT capability to address the regional hypersonic threat and will test that capability in the FY 2024 timeframe. MDA plans to accelerate the hypersonic missile defense program under a newly designated Glide Phase Intercept initiative to develop a capability to defeat a regional hypersonic threat. The eventual goal is providing greater depth of fire in a regional layered defense architecture. MDA is also pursuing advances in joint all-domain and global command and control to support USNORTHCOM in countering very long-range cruise missiles.

The Department's previous missile defense technology innovations have transitioned into weapon systems and vastly improved interceptor seeker capability, increased the speed and range of intercept with advances in propulsion, and increased the probability of single-shot kill using multifaceted tracking and discrimination algorithms. As an example, the technologies developed as part of the Multiple Object Kill Vehicle effort were presented to NGI bidders, and may be included in the proposals. Additionally, MDA invested in directed energy kill mechanisms, including multiple laser types, high-powered microwave, and component technologies to support development of sensors and interceptors, such as beam control and lethality. These investments allow the country to outpace the missile threat. We must continue to sustain, modernize, and expand the MDS by pursuing rapid, yet measured, development of advanced missile defense concepts and technologies for homeland and regional defense.

MDA is continually assessing emerging and disruptive technology for potential applications to missile defense utilization. Investments are being made in Artificial Intelligence, Machine Learning, Nanosat technology, Left-through-Right integration, Cybersecurity, and Quantum Science. Key to understanding the potential of technology has been the development of testbeds that allow MDA to exercise and demonstrate capabilities and test new concepts, algorithms, simulations, and software. MDA works extensively with partners, leveraging and expanding technology opportunities through cooperative, collaborative engagements with DoD partners, DoE labs, academia and U.S. allies and international partners.

MDA continues to drive for the inclusion of small businesses and universities through outreach, such as their Industry Innovation Summit and University Innovation Summit. These events present MDA's greatest technology challenges and offer one-on-one sessions for the Nation's most innovative minds to present their capabilities and solutions. MDA is committed to ensuring the use of small business to the maximum extent practicable, monitoring prime contractor performance to ensure contractors are achieving their proposed small business goals and objectives and have a mitigation plan in place to do so. MDA actively supports the DoD Mentor Protégé Program (MPP), currently overseeing five active DoD MPP agreements.

The MDA Small Business Advocacy Council (MDASBAC) consists of MDA large prime contractors dedicated to fostering and showcasing a superior collaborative environment to develop and promote successful small business relationships to achieve common goals. MDA has a robust outreach program and takes full advantage of the outreach resources administered by Procurement Technical Resource Centers/Small Business Development Centers to connect large defense contractors with viable small businesses to support the agency's mission.

SPACE DEVELOPMENT AGENCY

The Space Development Agency (SDA) was established in March 2019 to develop and field an alternative National Defense Space Architecture and accelerate the deployment of next-generation space capabilities to the warfighter. SDA is developing capabilities to address a wide range of national security space needs identified in the DoD Space Enterprise Vision of August 2018. To address current near-peer threats, SDA is focused on the most urgent of these needs by delivering a mesh network that will provide low-latency data transport in space to enable advanced missile tracking and beyond-line-of-sight targeting of land and maritime targets.

At its second anniversary in the Department, SDA has shown itself to be a "constructive disruptor" in national security space. Its model is tied to two main pillars: proliferation of satellites in Low-Earth Orbit (LEO) and spiral development, delivering new capabilities on-orbit every two years, starting in FY22. SDA's mission begins and ends with the warfighter, guiding SDA to stick to schedule so that needed capabilities are available for end users to address the threat at or ahead of need. The Agency has established a Warfighter Council to ensure the needs of the Combatant Commands, Services, Joint Staff, and Intelligence Community determine the minimum viable product for each tranche, or generation of satellites.

SDA is hitting its milestones and forming partnerships with the Services, Combatant Commands, and other DoD agencies to reduce risks and gain user insight. The agency delivered two satellites for launch nine months after receiving funding, was designated by the Department of Defense as the lead for the proliferated LEO Joint All-Domain Command and Control (JADC2) backbone, and awarded contracts for all four segments of its initial tranche. SDA is preparing to launch several capability demonstrations and risk-reduction experiments this year, in partnership with others from across the space enterprise, including DARPA, the Air Force Research Lab, Missile Defense Agency, and several small businesses developing state-of-the-art space technologies.

SDA actively seeks ways to leverage commercial advances in technology to enable its space architecture. New space companies are supplying satellites for the first generation of the architecture as well as the launch vehicle for that tranche. To kick off 2021, SDA published an update to the National Defense Space Architecture (NDSA) Systems, Technologies, and Emerging Capabilities (STEC) Broad Agency Announcement (BAA) seeking studies, technologies, and prototypes that enable Real-Time Global Awareness and Connectivity; Comprehensive Space-Based Sensing; and Omniscient Command, Control, and Execution. This BAA is in place to establish an "intellectual pipeline" to access ideas from across the community to inform the future architecture, enable leap-ahead improvements for future tranches, and enable new capability layers that address emerging warfighter needs. SDA is also focusing on maturing and transitioning technologies from America's small businesses, start-ups, and research institutions through a series of SBIR/STTR opportunities this spring.

In FY22, SDA will launch and operate the first tranche of satellites to demonstrate the Transport layer, the mesh network of communications satellites, and the Tracking layer, Overhead Persistent Infrared (OPIR) sensing satellites that provide missile warning, detection, and tracking capabilities. Tranche 1, the next generation of these capabilities, is slated for delivery in FY 2024, followed by future generations every two years that will incorporate battle management command and control and other layers of capability needed to provide persistent global access to protect national security. In FY23, the SDA will transition to the Space Force in accordance with the direction of the National Defense Authorization Act for FY 2020.

CONCLUSION

Our mission is to foster technological dominance across the Department of Defense, ensuring the unquestioned superiority of the American joint force. We are dedicated to ensuring that the technological edge remains in our favor. This statement while comprehensive, is not exhaustive in capturing all the activities being undertaken to maintain technological dominance in the present and future. The projects and programs contained in this statement do provide important examples of how crucial innovation is to the national security of the United States. I thank you for your time and I look forward to your questions.

Senator TESTER. Now we'll go to Dr. Tompkins for her statement.

STATEMENT OF DR. STEFANIE TOMPKINS, DIRECTOR, DEFENSE ADVANCED RESEARCH PROJECTS AGENCY

Dr. TOMPKINS. Chairman Tester, Ranking Member Shelby, and Members of the Subcommittee, thank you for the opportunity to testify today and for your strong support of DARPA over the years.

My name is Stefanie Tompkins, and I serve as the Director of the Defense Advanced Research Projects Agency or DARPA.

It's a real pleasure to be here with my friend and colleague Ms. Barbara McQuiston from the Office of the Under Secretary of Defense for Research and Engineering.

While we work closely with Ms. McQuiston's organization, DARPA has a unique mission in both the DOD community and the broader U.S. technology ecosystem. That mission is to prevent strategic surprise by making investments in breakthrough technologies for national security.

What that means is we anticipate, create, and demonstrate technologies that are nowhere on technology roadmaps and often outside most people's imaginations.

For over 60 years now, in partnership with innovators, inside and outside government, DARPA has repeatedly delivered on our mission. We've transformed revolutionary concepts and seemingly impossibilities into practical capabilities.

Examples of those capabilities include stealth technology, precision-guided weapons, unmanned aero-vehicles, as well as many icons in modern society, such as the Internet, automated voice recognition and language translation, and GPS receivers small enough to embed in nearly any consumer device.

Technologies like these provide more options for our Nation's leaders and the military services and today, with increasingly complex challenges and a rapidly-changing world, DARPA's role has never been more vital.

At DARPA, we think not just about scientific and engineering innovation now but also about the innovation ecosystem. That ecosystem includes many overlapping and adjacent communities from academia, industry, and government. It includes everything from fundamental research to global scale systems of systems. It includes innovation not only in technology but in processes and transition strategies, as well, and, most importantly, it includes a rotating cast of DARPA program managers who come from and will return to that ecosystem and who seek to solve not just today's problems but tomorrow's, as well.

One of the best illustrations of how DARPA works is related to the COVID–19 pandemic. So about 5 years ago, when I was serving in a different role at DARPA, I spent a lot of time on the road trying to expand and diversify our pro forma base.

One of the programs I talked about the most involved heavy investment into something called mRNA vaccines. So mRNA vaccines are pretty much a household word today, but at the time they were much, much more obscure and DARPA's investments were based on the insight of individual program managers who anticipated their need for both military and public health missions.

The research that DARPA first initiated more than a decade ago is now playing a leading and catalytic role in today's fight against COVID–19. In typical DARPA fashion, we made significant invest-

ments in the technology years before it was known to be needed, leading to high-impact capabilities related to prevention, diagnostics, and treatment that have helped to mitigate the current crisis.

From vaccines and diagnostics to defensive and offensive hypersonic technologies, state of the art artificial intelligence, quantum systems, micro-electronic solutions, and much, much more, DARPA has forged new paths and continues to deliver on our mission.

I look forward to working with the members of this subcommittee and others in Congress to ensure the security and resilience of our Nation, and I would be most pleased to answer your questions.

[The statement follows:]

PREPARED STATEMENT OF DR. STEFANIE TOMPKINS

Chairman Tester, Ranking Member Shelby and Members of the Subcommittee, thank you for the opportunity to testify before you today. I am Stefanie Tompkins, Director of the Defense Advanced Research Projects Agency, DARPA. It is a pleasure to be here with my colleague, Ms. Barbara McQuiston, from the office of the Undersecretary for Research and Engineering (USD(R&E)) in the Department of Defense. Our organizations work together every day to advance our Nation's defense technologies. DARPA plays a particular role in this community and in the broader U.S. technology ecosystem. That role is to anticipate, create, and demonstrate breakthrough technologies that are outside and beyond conventional approaches—technologies that hold the potential for extraordinary advances in national security capability.

For more than 60 years, DARPA has held to a singular and enduring mission: to make pivotal investments in breakthrough technologies for national security. Working with innovators inside and outside government, DARPA has repeatedly delivered on that mission, transforming revolutionary concepts and seeming impossibilities into practical capabilities. The results have included game-changing military capabilities like precision weapons, stealth technology, and unmanned aerial vehicles, as well as icons of modern civilian society such as the internet, automated voice recognition and language translation, and Global Positioning System receivers small enough to embed in myriad consumer devices.

DARPA creates and executes programs that rely on and inspire an innovation ecosystem of academic, corporate, and government partners. We focus on developing capabilities for national security leaders and the nation's military services, who work with us to create new strategic opportunities and novel tactical options. For decades, this interlocking ecosystem of collaborators has proven to nurture intense creativity. Today, DARPA's role has never been more vital. From being front and center in our nation's fight against the COVID–19 virus, to defensive as well as offensive hypersonics technologies, state of-the-art artificial intelligence, quantum technologies, and directed energy solutions, DARPA today is delivering on our most pressing security needs.

DARPA pursues game-changing technologies and capabilities in a way that provides surprising advantage for U.S. and Allied warfighters and at a much faster pace than the state of the art. DARPA's work with the Services and other agencies aims to meet not just known but as-yet unrecognized needs and move swiftly to deployment. That includes an increased emphasis on prototyping and joint projects—and, especially, a tighter emphasis on designing, building, and testing aspects of technology. Today, I will focus my testimony on how DARPA seeks to: 1) counter near-peer adversaries, 2) extend DARPA innovation to the warfighter and beyond, and 3) promote continued American innovation throughout the broader S&T ecosystem of university and industry partners.

1. Countering Near-Peer Adversaries

We seek to present adversaries with surprising warfighting scenarios that create dilemmas or completely disrupt their decision calculus. To do so, we must disrupt our own warfighting enterprises and provide decisive advantage across air, land, and sea, as well as space, cyberspace, and the electromagnetic spectrum. Big, monolithic platforms designed, built, and procured to do everything cost too much, take too long to field, and are usually technologically outdated by the time they are available. DARPA seeks a new asymmetric advantage—one that imposes complexity on

adversaries by harnessing the power of dynamic, coordinated, highly autonomous, and flexible architectures.

A. New Warfighting Constructs

Modern warfare is becoming less about singular platform and weapon capabilities, and more about combinations of systems that can be rapidly developed and composed into more effective warfighting constructs. DARPA's Assault Breaker II (ABII) and Mosaic initiatives, along with their resulting technologies, seek to fundamentally change the way the military thinks about designing, buying, and deploying future systems.

First, the ABII program addresses several challenges posed by our near-peer competitors. Patterned after the original Assault Breaker program in the late 1970's, a memorandum of agreement was signed by DARPA and the vice chiefs of all five Services to establish a joint service team creating technology solutions to these critical challenges. Interacting closely with the intelligence, military operator, and technology communities, the team's first objective is to design warfighting operational constructs based on new and emerging technologies and capabilities.

The program's second objective is to develop an advanced modelling and simulation environment to support analysis of true cross-domain (seafloor to space) cross-service warfighting constructs. Finally, the program is tying the advanced modelling and simulation environment into an interactive experiment environment to support exploration of highly complex, interdependent approaches that characterize the future of warfighting.

ABII seeks to organize this evolution in warfighting and act as a conduit to both communicate technology solutions to the services as well as articulate critical challenges to the technology development community in a manner where they can appreciate the larger picture. ABII will serve as the technical baseline for multi- domain operations moving forward.

In addition to ABII, DARPA has also been spearheading the "Mosaic" construct of future warfare. The Mosaic concept posits that using less expensive systems brought together on demand as the conflict unfolds, could facilitate the creation of "effects webs," enabling diverse, agile applications—from a kinetic engagement in a remote desert setting, to multiple small strike teams operating in a bustling megacity, or an information operation to counter an adversary spreading false information in a population threatening friendly forces and strategic objectives. Mosaics, therefore, can rapidly be tailored to accommodate available resources, adapt to dynamic threats, and be resilient to losses and attrition. Two Mosaic-related technologies—a novel decision aid for mission commanders and a rapid software integration tool—played a critical role in the recent Air Force demonstration of the Advanced Battle Management System (ABMS).

The Adapting Cross-domain Kill-webs (ACK) program and the System-of-systems Technology Integration Tool Chain for Heterogeneous Electronic Systems (STITCHES) were among a number of technologies employed late last summer in the ABMS on-ramp demonstration, which involved attacks using live aircraft, ships, air defense batteries, and other assets. ACK is developing a decision aid for mission commanders to assist them with rapidly identifying and selecting options for tasking—and re-tasking—assets within and across organizational boundaries. Specifically, ACK assists users with selecting sensors, effectors, and support elements across military domains (space, air, land, surface, subsurface, and cyber) that span the different military services to deliver desired effects on targets. Instead of limited, monolithic, pre-defined kill chains, these more disaggregated forces can be used to formulate adaptive "kill webs" based on all of the options available.

ACK was used in an air defense scenario during the ABMS demonstration, where an air commander faced incoming aerial threats and needed to quickly decide the best way to counter them. In the demo, the ACK decision aid software analyzed thousands of options to form cross-domain kill-webs and recommended assets and the best command-and-control "play" to the mission commander.

The machine-to-machine communications to enable this distributed fire control was performed by the STITCHES integration toolchain. STITCHES is a software-only and fully government owned (non-proprietary) toolchain specifically designed to rapidly integrate heterogeneous systems across any domain. STITCHES innovation is in auto-generating middleware between systems without needing to upgrade hardware or breaking into existing system software. The toolchain does not force a common interface standard; rather it rapidly creates the needed connections based on existing fielded capabilities obviating the need to upgrade in order to interoperate.

B. Responsive and Flexible Space Operations

The Department of Defense has prioritized rapid acquisition of small satellite and launch capabilities. Through leveraging commercial acquisition practices, DARPA has been able to streamline a number of militarily-relevant missions in the last year from conception through services acquisition and launch. These missions are validating emerging concepts for resilient capabilities that would reside in low Earth orbit—a capability which will revolutionize communications, intelligence, surveillance, and reconnaissance.

Right now, satellites critical to our national security and warfighting capabilities traditionally are custom designed. In the increasingly contested space environment, these exquisite yet costly and monolithic systems have become vulnerable targets that would take years to replace if degraded or destroyed.

Meanwhile, the evolution of commercial space has led to the design and manufacturing of LEO constellations intended for broadband internet service, which could offer previously unavailable economies of scale. DARPA is interested in leveraging these advances through our Blackjack program and driving them forward in order to demonstrate military utility.

Blackjack aims to develop and demonstrate the critical technical elements for building a global high-speed network backbone in low Earth orbit. That would enable highly networked, resilient, and persistent DoD payloads that provide over-the-horizon sensing, signals, and communication, and hold the ground, surface, and air domains in constant global custody. To do that, researchers are investigating innovative vehicle delivery approaches that enable revolutionary advances in payload size, weight, power, and cost.

For Blackjack, we are targeting a series of risk reduction rideshare flights that will continue through this year. With these flights, the goal is to develop and validate the technologies necessary for the Blackjack constellation.

C. Attribution of Malicious Cyber Actors

DARPA researchers are identifying and addressing critical cyber vulnerabilities that threaten global stability and security. Malicious actors in cyberspace currently operate with little fear of being caught due to the fact that it is extremely difficult, in some cases perhaps even impossible, to attribute malicious actions in cyberspace to specific individuals. The reason cyber attribution is difficult stems at least in part from a lack of end-to-end accountability in the current internet infrastructure.

To address this problem, DARPA launched the Enhanced Attribution (EA) program. EA is making currently opaque malicious cyber adversary actions and individual cyber operator attribution transparent by providing high-fidelity visibility into all aspects of malicious cyber operator actions. Furthermore, if successful, EA will increase the government's ability to publicly reveal the actions of individual malicious cyber operators without damaging sources and methods. Over the last three years the program has developed techniques and tools for generating operationally and tactically relevant information about multiple concurrent independent malicious cyber campaigns, each involving several operators, and the means to share such information with U.S. law enforcement, intelligence, and Allied partners.

Late last year, DARPA EA researchers used their data analytics to develop timely, accurate threat information regarding Russian-attributed malicious cyber infrastructure and associated actor personas. EA shared this information with close partners at the FBI Atlanta and Pittsburgh field offices, contributing to the October 2020 indictment of six GRU personnel associated with a worldwide destructive malware campaign and the remediation of that malware campaign in U.S. and Allied critical infrastructure.

D. Hypersonics

The ability to field hypersonic systems ranks high on the DoD's list of priority technologies, due in part to the pace of research by peer adversaries. Hypersonic flight at velocities of more than five times the speed of sound offers major advantages on the tactical battlefield, especially for conducting military operations from longer ranges, with shorter response times, and enhanced effectiveness compared to current military systems.

DARPA is developing technology demonstrations in 2021 for a number of operational capabilities. For example, the Hypersonic Air-breathing Weapon Concept (HAWC) program is a joint effort with the U.S. Air Force (USAF) seeking to develop and demonstrate critical technologies to enable an effective and affordable air-launched hypersonic cruise missile. The program emphasizes efficient, rapid, and affordable flight tests to validate key technologies. HAWC is pursuing flight demonstrations to address three vital technology challenge areas: air vehicle feasibility, effectiveness, and affordability.

The Tactical Boost Glide (TBG) program is another joint DARPA/USAF undertaking, striving to develop and demonstrate technologies to enable future air-launched, tactical-range hypersonic boost glide systems. In such systems, a rocket accelerates its payload to high speeds, the payload then separates from the rocket, and glides unpowered to its destination. TBG plans to include ground and flight-testing in 2021 to mature critical technologies and demonstrate system performance.

2. Innovations for the Warfighter and Beyond

A. Stopping Pandemics

A primary aim of the DARPA Biological Technologies Office (BTO) is to improve total force health protection and readiness. One of the biggest vulnerabilities to deployed military personnel and civilians is a lack of protection against many endemic and emerging bio-threats (e.g., the ongoing COVID–19 pandemic, or mosquito-borne viruses such as Chikungunya and Dengue).

DARPA's approach to pandemic prevention advanced the current state of the art by enabling antibody discovery in days to weeks rather than months to years. Additionally, DARPA investments in new diagnostic platforms allowed researchers to pivot rapidly to emergent viruses such as COVID–19. In 2011, DARPA began investing in gene-encoded vaccines based on DNA or RNA. Unlike traditional vaccines, which nearly all require laborious, expensive, and lengthy development times to counter each new threat, gene-based vaccines have the advantage of directly delivering coded genetic instructions to the body on how to produce its own protective antibodies against a specific threat. This means gene-encoded vaccines can be easily manufactured at scale using largely synthetic processes, versus being cultured in eggs; transported and stored without many of the cold-chain logistics required by traditional medical countermeasures; delivered with near-immediate efficacy; and safely expressed in the body for only a limited duration, causing no permanent alteration to the genome. This approach has shown great promise as a means to provide safe, reproducible, long-term immune protection. However, vaccines often require more than one dose and weeks to months before protected status is achieved, creating vulnerability either directly to warfighters if they are deployed before immunity has been established or to the mission due to the delayed deployment of personnel until they achieve immune protection.

DARPA's fundamental research and development (R&D) investments, fortunately, have resulted in discovery of several gene-encoded monoclonal antibody platforms, and has greatly de-risked the gene- based medical countermeasure (MCM) field. DARPA R&D investments have catalyzed significant commercial and transition interest. Several companies (including Moderna, AstraZeneca, and Inovio) have made major investments in the budding field of gene-encoded MCMs and have released vaccines to curb the spread of COVID–19. DARPA investments also spurred spin-out companies such as RenBio, which is optimizing the delivery of gene-based MCMs for increased efficacy and tolerability.

Early in 2020, DARPA allied closely with department medical and chem/bio defense organizations as well as Health and Human Services (HHS) components to join the fight against COVID–19. Many of these intergovernmental allies—including the DoD's Joint Program Executive Office for Chemical and Biologic Defense (JPEO CBD), the HHS Biomedical Advanced Research and Development Authority (BARDA), and the HHS National Institute of Allergy and Infectious Disease (NIAID)—partner with DARPA to perform advanced development after our initial investments, ensuring the scale-up and distribution of novel medical countermeasures.

Building on existing DARPA investments to accelerate the discovery of novel countermeasures, DARPA-funded researchers were responsible for discovering therapeutics—antibodies—from blood samples of recovered coronavirus patients. DARPA also partnered with advanced developers (public and private) to manufacture at scale using DNA/RNA techniques in addition to traditional cell-based biomanufacturing.

B. Extending the "Golden Hour"

When a Service member suffers a traumatic injury or acute infection, the time from event to first medical treatment is usually the single most significant factor in determining the outcome between life and death. First responders must act as quickly as possible, first to ensure a patient's survival and then to prevent permanent disability. The Department of Defense refers to this critical, initial window of time as the "golden hour," but in many cases the opportunity to successfully intervene may be less than sixty minutes, which is why the military invests so heavily in moving casualties as rapidly as possible from the battlefield to suitable medical

facilities. However, due to the realities of combat, there are often hard limits to the availability of rapid medical transport and emergency care.

DARPA created the Biostasis program in 2018 to develop new possibilities for extending the golden hour, not by improving logistics or battlefield care, but by going after time itself, at least how the body manages it. Biostasis is attempting to address the need for additional time in continuously operating biological systems faced with catastrophic, life-threatening events. The program leverages molecular biology to control temporarily the speed at which living systems operate, and thus extend the window of time following a damaging event before a system collapses. Essentially, the concept aims to slow life to save life.

C. Serving Wounded Veterans

With a focus on wounded warriors and facilitating their return to military service, the Hand Proprioception and Touch Interfaces (HAPTIX) program is pursuing key technologies to enable precision control of and sensory feedback from sensor-equipped upper-limb prosthetic devices. If successful, the resulting system would provide users near-natural control of prosthetic hands and arms via bi-directional peripheral nerve implants. The program has a strong focus on technology transition and aims to create clinically relevant technology in support of wounded warriors suffering from single or multiple limb loss.

HAPTIX builds on prior DARPA investments in the Reliable Neural-Interface Technology (RE–NET) program, which created novel neural interface systems that overcame previous sensor reliability issues (sensors now last for the lifetime of the patient). A key focus of HAPTIX is on creating new technologies to interface permanently and continuously with the peripheral nerves in humans. HAPTIX researchers are designing technologies to tap into the motor and sensory signals of the arm to allow users to control and sense the prosthesis via the same neural signaling pathways used for intact limbs. Direct access to these natural control signals will, if successful, enable more natural, intuitive control of complex hand movements, and the addition of sensory feedback will further improve prosthetic hand functionality by enabling users to sense grip force and hand posture. Sensory feedback may also provide important psychological benefits such as improving prosthesis "embodiment" and reducing the phantom limb pain that is suffered by approximately 80 percent of amputees.

In addition to seeking to return sensation to amputees, DARPA is also aggressively investigating technical solutions to spinal cord injury (SCI), which is of significant concern to the Department of Defense. Of the 337,000 Americans with serious SCIs, approximately 44,000 are veterans, with 11,000 new injuries occurring each year. SCI is a complex condition—the injured often face lifelong paralysis and increased long-term morbidity due to factors such as sepsis and autonomic nervous system dysfunction. While considerable research efforts have been devoted toward restorative and therapeutic technologies to SCIs, significant challenges remain.

DARPA's Bridging the Gap Plus (BG+) program aims to develop new approaches to treating SCI by integrating injury stabilization, regenerative therapy, and functional restoration. Last year, DARPA announced the award of contracts to a handful of university researchers to advance this crucial work. Multidisciplinary teams at each of these universities are tasked with developing systems of implantable, adaptive devices that aim to reduce injury effects during early phases of SCI, and potentially restore function during the later chronic phase.

3. Promoting American Innovation

One of the classic models of technology development begins with basic research that uncovers a new principle or phenomenon, which innovators then apply and develop into a new capability that enables people to do more than they could before. This model cannot account for the origin of all of the technologies DARPA has had a hand in, but it applies to many of them. Indeed, DARPA's job is to change what's possible—to do the fundamental research, the proof of principle, and the early stages of technology development that take "impossible" ideas through "implausible" and then to, surprisingly, "possible" or even "likely." No other DoD agency has the mission of working on projects with such a high possibility of producing truly revolutionary new capabilities—or such a high possibility of failure. A big part of DARPA's expertise is seeking high pay off capabilities by managing risk in ways that help keep the innovation pipeline flowing. The following are examples of the kinds of foundational efforts that promise to impact national security just like other DARPA "firsts," including the ARPAnet, miniaturized GPS, stealth aircraft, UAVs, and monoclonal antibody therapeutics.

A. Artificial Intelligence

DARPA has been a leader in artificial intelligence since the 1960s. We played key roles in realizing the first and second waves of AI (first rule-based, then statistical-learning-based), and now we are working to realize the third wave, which can be described as contextual adaptation. To better define a path forward, DARPA announced in September 2018 a multi-year investment of over $2 billion in new and existing programs called the "AI Next" campaign.

Currently, DARPA is pursing more than 30 programs that are exploring ways to advance the state-of-the-art in AI, pushing beyond second-wave machine learning techniques towards contextual reasoning capabilities. In addition, more than 60 active programs are applying AI in some capacity, from agents collaborating to share electromagnetic spectrum bandwidth to detecting and patching cyber vulnerabilities.

Under the AI Next campaign, key areas being explored include automating critical DoD business processes; improving the robustness and reliability of AI systems; enhancing the security and resiliency of machine learning and AI technologies; reducing power, data, and performance inefficiencies; and pioneering the next generation of AI algorithms and applications, such as "explainability" and commonsense reasoning.

DARPA also announced a quick-turn funding mechanism called Artificial Intelligence Exploration (AIE) that allows us to quickly test the feasibility of AI concepts by rapidly developing prototypes. AIE Opportunities are released on a rolling basis from across DARPA's portfolio, providing awards in as little as 90 days of up to $1 million each for 18-month periods of performance. During these periods of performance, very high-risk, high-reward topics will be investigated with the goal of determining feasibility and clarifying whether the area is ready for increased investment. The ultimate goal of each AIE Opportunity is to invest in research that leads to prototype development that may result in new, game-changing AI technologies for U.S. national security. To date, we have made 141 contract awards for more than 20 AIE topics.

A representative example of DARPA's AI Next campaign is the Assured Autonomy program, which is working to provide continual assurance of a learning enabled cyber physical system's (LE–CPS) safety and functional correctness. The program is developing mathematically verifiable approaches and tools that can be applied to different types and applications of data-driven machine learning algorithms in an LE–CPS to enhance their autonomy and assure they are achieving an acceptable level of safety. To help ground the research objectives, the program is prioritizing challenge problems in the defense-relevant autonomous vehicle space, specifically related to air, land, and underwater platforms.

To assess the technologies in development, research teams integrated them into a small number of autonomous demonstration systems and evaluated each against various defense-relevant challenges. After 18 months of research and development on the assurance methods, tools, and learning enabled capabilities (LECs), the program is exhibiting early signs of progress.

During a recent demonstration, DARPA researchers integrated tools with an Iron Bird X-Plane simulation and a small test bed aircraft, and tested them against challenge problems relevant to ground operations, specifically assuring taxi operations on an airfield or aircraft carrier deck.

During the live aircraft exercise, the assurance methods were able to detect the presence of an obstacle during taxi, which triggered a safety that identified and executed a response route around the obstacle. The assurance methods also detected when the camera feed was being noised or obscured, kicking-in a safety method that identified and executed what it deemed the safest response—stopping the aircraft until it could safely resume operations. Additionally, the tools were able to detect anomalies that could cause their LEC to misbehave, and allowed the system to maintain safe operations despite those anomalies. Further, the use of formal models and specifications provided assurances about the system's safety both at design and run time.

B. Microelectronics

In June 2017, DARPA announced the Electronics Resurgence Initiative (ERI) as a bold response to several technical and economic trends in the microelectronics sector. Among these trends, the rapid increase in the cost and complexity of advanced microelectronics design and manufacture is challenging a half-century of progress under Moore's Law, which holds that the number of transistors per silicon chip doubles about every two years. Meanwhile, non-market foreign forces are working to shift the electronics innovation engine overseas, while cost-driven foundry consolidation has limited DoD access to leading-edge electronics, challenging U.S. economic and security advantages. Moreover, highly publicized challenges to the nation's dig-

ital backbone are fostering a new appreciation for electronics security—a longtime defense concern.

Building on the tradition of other successful government-industry partnerships, ERI aims to forge forward-looking collaborations among the commercial electronics community, defense industrial base, university researchers, and the DoD to address these challenges. There is significant historical precedent to suggest the viability of this approach, as each wave of modern electronics development has benefitted from the combination of defense-funded academic research and commercial sector investment.

Given today's cost, complexity, and security challenges, it is critical that the nation collaboratively innovate on the next generation of electronics advancement. DARPA envisions four key areas of development—3D heterogeneous integration, new materials & devices, specialized functions, and design & security—each of which have been central to ERI since its inception. Leveraging 3D heterogeneous integration, the next wave should support continuing electronics progress despite challenges to traditional silicon scaling. This integration will enable innovators to both add new materials and devices to the silicon foundation and create specialized functions precisely designed to meet the diverse needs of the commercial and defense sectors. To manage the complexity of working in three dimensions, the next wave will also demand new architectures and design tools that address rising design costs, enable rapid system upgrades, and make security integration a primary design concern. Several technological advancements developed in the DARPA CHIPS, PIPES, and HI3 programs are in transition leveraging SOTA commercial manufacturers in the OUSD(R&E) the State-of-the-art (SOTA) Heterogeneous Integrated Packaging (SHIP) program. This is a critical microelectronics performance enabler for DoD modernization priorities, including hypersonics, Artificial Intelligence, 5G, Cyber, and Space.

C. 5G Networks

Emerging 5G mobile wireless networking technologies are slated to dramatically increase in both scale and speed, enabling much faster access to data collected from billions of connected devices (60 billion nodes by 2023). This supercharged information highway is envisioned to play an important role across many industries, ranging from medicine to manufacturing. Major advances in 5G will make it easier to customize the network at a wide variety of locations. This new flexibility offers many benefits, but at the same time introduces novel security challenges. Today's proprietary 5G technologies make it difficult to achieve the transparency necessary for security-related risk analysis and mitigation. This lack of security assurance makes it harder to deploy these technologies for defense capabilities.

In 2020, DARPA created the Open, Programmable, Secure 5G (OPS–5G) program to tackle many of the security challenges facing future wireless networks. OPS–5G is exploring the development of a portable, standards-compliant network stack for 5G mobile networks that is open source, and secure by design. The program seeks to enable a "plug-and-play" approach to various network software and hardware components, which reduces reliance on untrusted technology sources. OPS–5G will also explore the development of cost-effective SWaP-conscious cryptography with scalable security protocols. Overall, the goal of OPS–5G is to enable more secure 5G as well as future generations of networks beyond 5G.

D. Quantum Information Science

Quantum information science (QIS) includes computation, communication, and sensing technologies that exploit our understanding of quantum mechanics. Theory promises significant advances over the state of the art, with some practical successes, but much of the QIS field remains technically nascent. The successes are largely related to sensors that deliver exquisite sensitive measurements in small packages. For the DoD, this supports RF devices for radar and communications, it also enables precise stable measurement of time—useful for communication and for navigation. Much has been published on the use of quantum technology for secure communications, a technical area that saw successful DARPA investments over a decade ago. The capabilities promised by theorists for quantum computation have been more elusive. The notion of a quantum computer that can outperform conventional computers to solve useful problems is attractive, but in practice has not been possible to achieve.

DARPA is currently pursuing basic and applied QIS research. One program aims to produce small portable devices that maintain GPS-quality time and position for weeks—in the absence of GPS signals. Another program seeks to understand what may be the limits of electromagnetic sensing using clouds of atoms. Several programs explore aspects of quantum computation to determine which approach offers

the most promise for substantial practical advantage. These computation efforts include two of note: how to use a moderate number of imperfect quantum bits, while another seeks to bring rigor to the fledgling quantum computing marketplace with the introduction of insightful benchmarking. There is much valuable science that quantum-based computation may make possible in diverse fields including material science, machine learning, and biology, but it remains a DARPA-hard field in which to work.

E. Nurturing the Innovation Base

Over the past two years, DARPA's Embedded Entrepreneurship Initiative (EEI) pilot program has helped 30 pre-seed research teams raise over $100 million in U.S. investment, spin out a dozen new companies, establish numerous joint development agreements with corporate partners, and commission multiple manufacturing facilities. In February of this year, DARPA launched an expansion of EEI with the goal of accelerating 150 DARPA-backed technologies out of the lab and into products that promise to fundamentally change the way we live, work, and fight. The initiative augments technical research teams with critical entrepreneurial expertise, top-tier commercialization mentors, and provides connections to investors. This important work delivers an effective counter to aggressive foreign investors by building stronger companies that have the ability to attract U.S. capital.

In this effort, DARPA is teaming with IQT Emerge, a new organization within In-Q-Tel (IQT) that provides entrepreneurial expertise as well as connections to early-stage U.S. investors. IQT Emerge leverages IQT's unique place at the intersection of venture capital, government, and the startup community to keep the national security community at the forefront of technology innovation.

EEI provides catalytic funding, mentorship, and investor and corporate connections for select DARPA researchers. Resources include: an average of $250,000 in non-dilutive funding to hire a seasoned entrepreneur or business executive for one to two years with the goal of developing a robust go-to-market strategy for both defense and commercial markets; dedicated commercialization mentors with extensive private sector experience; and engagement with DARPA's private sector Transition Working Group comprising over 100 top-tier U.S. investors and corporations key to scaling and supply chain development.

DARPA-funded scientists and engineers are an invaluable resource for national competitiveness. Supporting these researchers with tailored business expertise to advance their innovations for public and military use is critical to obtain the full benefit from taxpayer funded R&D investments.

Since 2018, roughly the same time frame from the inception of EEI, DARPA has also stepped up its outreach to university researchers. Security concerns in recent years have significantly increased the barriers to university research for the DoD, and better communication of opportunities and expectations is critical to minimizing those barriers. DARPA's academic outreach initiative began in earnest with visits to a handful of public universities. During the pandemic, however, the agency was forced to change tactics and hosted a large virtual event in September 2020 called the "DARPA Vice Presidents and Chancellors of Research Summit." The Summit attracted 223 representatives from 126 schools across the nation; twenty percent of the schools had never done business with the agency. During the three-hour summit, participants learned about the agency's near-term investment priorities and how to pursue funding opportunities through existing contract vehicles.

In addition to small business and university outreach efforts currently underway, DARPA also has three formal programs aimed at supporting the next generation of researchers. The first effort is the Joint University Microelectronics Program (JUMP). JUMP is a major public/private initiative that includes several leading companies from the semiconductor and defense industries such as Intel, IBM, Micron, Analog Devices, EMD Performance Materials, ARM, Samsung, TSMC, Raytheon, Northrop Grumman, and Lockheed Martin who have tasked six research centers to undertake high-risk, high-payoff research that addresses existing and emerging challenges in microelectronic technologies. JUMP comes at an inflection point in the history of the semiconductor industry where application and system research are critical to enabling the development of superior electronic systems to meet DoD and commercial needs.

Under JUMP, the challenges of the "application-centric" research centers focus on accomplishing application-oriented goals and spurring the development of complex systems with capabilities well beyond those available today. Diving deep into cognitive computing, intelligent memory and storage, distributed computing and networking, and radio frequency (RF) to terahertz (THz) sensor and communications systems, among other areas, these research centers are developing systems that will

be transferable to military and industry in a five year timeframe and ready for field deployment in ten years.

Also, earlier this year, DARPA announced a post-doctoral fellowship program for talented young scientists, engineers, and mathematicians in the field of computer science with grants sized to support each fellow for up to two years. Participation in DARPA's new program is open to current U.S. citizens and permanent residents who have received a Ph.D. degree no earlier than June 2019 or who will have received a Ph.D. prior to the date of award, and who will be appointed to a postdoctoral position at a U.S. institution of higher education during the 2021–22 academic year.

The longest running program that DARPA has supporting university researchers is the Young Faculty Awards (YFA), which has been providing funding opportunities since 2006 as a forward-looking way to familiarize rising researchers in junior positions with national-security-relevant work within the DoD. The YFA program provides funding, mentoring, as well as industry and DoD contacts to awardees early in their careers with the long-term goal of developing the next generation of academic scientists, engineers, and mathematicians who will focus a significant portion of their career on national security issues. To date, 447 researchers from 40 states have participated in the YFA program.

CONCLUSION

From DARPA's perspective, the technological future—the endless frontier—is enormously attractive, bright with opportunities, but also fraught with unanticipated risks. For more than 60 years, the men and women of DARPA have taken very seriously their unique mission to serve the Nation by preventing—and when necessary fomenting—technological surprise.

Although I have just recently returned to DARPA, it is clear to me that we are stronger and more committed to that mission than ever. I look forward to working with the members of this subcommittee and others in the Legislative and Executive branches to ensure that the United States maintains its historic lead in the investigation and development of powerful technologies, in addition to their safe and responsible application in support of a more stable, secure, and sustainable world.

Senator TESTER. Thank you, Dr. Tompkins, for your testimony.

Because Senator Durbin has a commitment for the Memorial Service, I'm going to recognize him first.

Senator Durbin: Thank you very much, Mr. Chairman, and thank you to the witnesses who have joined us today.

I guess my opening question is not going to be specific to any area of innovation but just very generic.

If you ask the Department of Defense and previous Administrations and I'll bet in this one, as well, who are our hard targets, who are our major adversaries in the world, they would usually report four pretty obvious ones, China, Russia, North Korea, and Iran, and then if you'd ask a follow-up question, how much do each of these major adversaries spend in their annual budget for their military, you would find numbers that range from very small to still very modest in comparison to the United States.

The reason I raise this question regularly is we spend more than all of the other nations in the world on defense and security. We certainly want to be safe as a Nation, but it's our job here in this committee to ask a question, are we getting our money's worth out of this, and when it comes to innovation, I noticed, Ms. McQuiston, in your statement, as well as the statement by Dr. Tompkins, there was reference to competition with adversaries.

You would think when you consider the hundreds of billions of dollars that we spend each year, that that would hardly ever be the case. It's like a high school team regularly beating the New York Yankees. You just don't expect that to happen when you compare the resources that are being dedicated.

Can you put innovation in that context and ask whether or not our investment in innovation gives us a natural lead, an acquired lead in this competition that the budget figures belie?

Ms. MCQUISTON. I will take that answer. We're very lucky. We just started the Innovation Steering Group under Deputy Secretary Hicks, and what we're doing in innovation is looking across the DOD as transforming a lot of the processes in order to be better adaptors of technology and to more efficiently and rapidly modernize.

Our services have the burden sometimes of having the legacy systems and the newer technologies and disruptive technologies coming onboard. We're moving modernization ahead, but we can always do it better and more innovatively.

When I think of innovation, I think of two things: efficiency and effectiveness. So efficiency is doing things right and effectiveness is doing the right thing. So with the range of new technologies that can be adopted at a greater speed for us, I believe that we can come up to par and actually exceed the market and our competitors.

Senator DURBIN. So I've read some histories of DARPA, Pentagon's Brain, and books like that, very impressive, and I notice that time and again there was disruptive thinking and planning and some of it fell flat on its face but that's to be expected.

So I guess my question is as we fund things already discovered with massive amounts of taxpayers' dollars, how do you combat the fighting the last war syndrome and establishment syndrome that says we've got to keep doing more of what we've done before, and how do you get into asymmetrical thinking in an establishment as large as the Department of Defense?

Ms. MCQUISTON. The Disruptive Innovation Unit that we have under Research and Engineering has that mission entirely because they're working with the National Security Innovation Network, the National Security Capital, and bringing in market innovations and commercialized technologies. With the activities to date, they have a 189 companies now on contract. 75 percent are small business, 32 percent are first-time vendors, and 10 percent have already transitioned into military use, and that's the key, to be flexible and to work at speed, at commercial speed in order to integrate the technology rapidly into the service.

At the same time, we need to understand what the disruptive technology can mean for our advantage and also for the needs within the military, so war gaming and putting together exercises and demonstration to show what could be capable.

As DARPA can show you, a lot of times we put the needs and the requirements forward but oftentimes the newer technology is a capability that no one even concede would have been possible. So it's the merging of the future with the needs of today that actually will keep technology in the leading edge and keep us competitive with the national security and the economic security of our country.

Senator DURBIN. Thank you, Mr. Chairman.

Senator TESTER. Senator Shelby.

Senator SHELBY. Thank you, Mr. Chairman. Thank you for this hearing. I think it's very important.

As I said earlier, I don't know what we can get into that's sensitive in this open hearing today, but the Chairman has indicated that we will have a closed hearing and hope to get you back and so forth.

In the area of quantum and artificial intelligence, China and Russia, you know, we all know, are advancing their military technologies always, and increasing their defense budgets at alarming rates.

How is the department continuing to reform its processes and investment decisions to ensure that the U.S. will maintain the technical dominance necessary to deter our adversaries, and what can you speak to in this area? I don't know.

Ms. MCQUISTON. Well, there's a few things I can speak to. We have been looking at quantum from the scientific side probably at least 20 years or more, but we've had success——

Senator SHELBY. Touch on how important quantum computing is if we can ever work it all out, and it's also important to our adversaries, is it not?

Ms. MCQUISTON. Yes, actually, the future of network technology and security will greatly rely on quantum technology, and DARPA, I know, has had initiatives in this area.

I'm happy to say that a lot of them are starting to see commercialization, as well. So I think our investment in that area is starting to pay off. So I think you will actually see more activity on there.

Some of the technologies we can brief you in another venue.

Senator SHELBY. What trade-offs in the area of hypersonics are we having to make as it relates to weapon development and fielding which would come with it due to resource constraints? Are you getting what you need at DARPA for this sensitive, very important research?

Dr. TOMPKINS. Yes, sir. To the extent that I can——

Senator SHELBY. Go ahead.

Dr. TOMPKINS [continuing]. Discuss this in this hearing, the support that we have on our hypersonics program, both offensive and defensive, is adequate and we can go into more details on tradeoffs in a different venue.

Senator SHELBY. Okay. In the area of space development, 2 years ago the Space Development Agency was created to accelerate the development and fielding of the next generation space capabilities.

Where we are there today and where are our adversaries?

Ms. MCQUISTON. Well, I'm happy to say for what the Space Development Agency has put together is rapidly developing new space architectures and commercial development processes in alignment with capabilities and speed.

We're integrating ground stations for advanced data links at Fort Greely, Alaska. We're working with putting forward constructive disruptors for operations at LEO (Low Earth Orbit). The first satellite demonstrations for communication are scheduled for fiscal year 2022, and working on what I would call commercial speeds, commercial launch speeds and setting up satellite operations at Grand Forks and at Redstone Arsenal.

I really do believe that speed and adaptation of spiral development and what we already see in commercial launch processes is

where we need to step up in timing for being able to put our capability up in space. So, again, if we want to talk specifics on where we are tactically in another venue, we would be happy to go into that.

Senator SHELBY. Thank you. Dr. Tompkins, in the area of cyber technology, how important is quantum computing and hopefully good research coming out of there? What will that do for us, hopefully do for us?

Dr. TOMPKINS. So in cyber technology, quantum computing offers a few different opportunity spaces.

One obviously is in the area of quantum encryption which I think has been most broadly discussed. The other, I think, is in the area of quantum computing and simulation, which then allows us to solve different kinds of optimization and sort of complexity-type problems, which would allow us to focus on analyzing, understanding, modeling, and predicting a much wider range of potential cyber behaviors and activities, and then, similarly, defending against them.

Senator SHELBY. Dr. Tompkins, one more question, if I could. In the area of hypersonics, we all know that we've got a challenge there as far as developing the hypersonic offensive weapon and also defending against it.

Where are we today, and what kind of timeframe do you think we have before we can really field what we need for the security of the country?

Dr. TOMPKINS. So DARPA has two initiatives in the defensive hypersonics arena. Details of both obviously, as you had mentioned, are going to have to go into a different session.

There is one very specifically, the Program Glide Breaker, in which we're working closely with NDA to derisk certain key aspects of the overall technology space. The timing of exactly when the transition of those technologies would go into a broader end-to-end system.

I think it's both a conversation that goes beyond just DARPA but also does require the ability to talk in a closed setting.

Senator SHELBY. Thank you. Mr. Chairman, thank you for your indulgence.

Senator TESTER. Yes. Thank you, Senator Shelby.

Ms. McQuiston, I want to touch on a couple things. I want to touch on, Number 1, our competitiveness compared to where we were 5 or 10 years ago and how you assess our success. I know you talked about war gaming, I want to get into that a little more, but let's start with our competitiveness compared to where we were. Are we ahead, behind?

Ms. MCQUISTON. I think the United States is one of the best innovators of technology overall. I think that we have some of the brightest people, the determination, the freedom, the flexible financial systems, and the determination to really succeed.

To match that with the Department of Defense, we need to have the same innovative culture as we have in our commercial industry. That's why adoption of commercial technology at the speed of which activities occur in the commercial world will be critical to more rapidly be able to gain the capabilities that the new technology and modernization will give to the military.

We are in a good position but we can always be in a much better one.

Senator TESTER. So is it fair to say, by what you've just said, that we are more competitive today than we were 5 or 10 years ago?

Ms. MCQUISTON. I believe we are, and I believe it's because we are modernizing.

Senator TESTER. Okay. And then how do you assess that competitiveness? How do you assess, you know, defining where we're at?

Ms. MCQUISTON. Well, you know, in an open session along this line, I would actually point to the vaccine technology. We've been thinking a lot about new frontiers, about challenges that the world is facing right now, and we've been thinking about them and doing things for awhile, and so surprises never come—disruptive technology never comes out of the blue.

DARPA has been our great jewel in being able to anticipate these things and start the technology ecosystem in new capabilities that have really been transformational for the United States.

Senator TESTER. Okay. So one more, and that is, innovative technologies cover a wide range, how are we prioritizing those investments, and could you give me a preview of the Administration's priorities? They may be the same answer for both questions.

Ms. MCQUISTON. At Research and Engineering, the Office of Modernization currently has 11 priorities. They fold into a lot of what is going on relative to being able to add capabilities, such as in AI (Artificial Intelligence), hypersonics, other areas of the 11 modernization techniques. Some of them will be more mature and able to have rapid adaptation. Other technologies will need more time, based on its development. That said, I do believe we can move faster to adopt those technologies.

With regards to where they stand with the Administration, the Secretary of Defense and the prioritizations, I would defer to the agency overall.

Senator TESTER. Okay. Dr. Tompkins, DARPA invented the Internet for the Department of Defense. It was adopted worldwide.

You talked about the mRNA vaccines. Are you working on any other technologies that have broader appeal beyond the Department of Defense, Dr. Tompkins?

Dr. TOMPKINS. Certainly. One example would be work that we're doing in 5G technologies for communications. So, you know, 5G is one of those areas which suffers a little bit from siloed, proprietary, vendor-driven capabilities, and so DARPA has a program called Open Co-fundable and Secure 5G, which basically seeks to create an open source 5G capability which would open up both from military perspectives and also ultimately from commercial/economic perspectives the power of 5G for a wide range of sort of dual-use capabilities.

Senator TESTER. All right. I'm going to go to Senator Moran.

Senator MORAN. Mr. Chairman, thank you very much. Thank both of our witnesses for joining us.

Let me begin by asking a question of Dr. Tompkins about cybersecurity. This has been a priority of mine and we have lots of reasons for that to be the case. It's important, but could you describe

for me how mosaics and other related cyber initiatives will not only support the department's cyber defense but the industrial partners that are critical to our Nation's security?

Dr. TOMPKINS. Certainly. So DARPA has a fairly large number of different programs focusing on cybersecurity with priorities in the areas of prevention, so things like network operations analytics, but as well as looking at topics in the area of attack attribution and graceful degradation and recovery because we do understand that as long as we are in defense, we also have to be prepared for the attack that does get through.

In those cases, they are looking not only at military systems but they translate very naturally to corporate systems. They translate to infrastructure systems, such as, you know, the power grid, water supply security, and many others.

Senator MORAN. Are those programs receiving the support they need to deploy new capabilities from the lab to the force?

Dr. TOMPKINS. Yes, sir, I do believe they are. One of the really nice things about cyber technologies, especially if they are mainly for system software, is that they transition much more naturally and much more quickly than a lot of hardware-focused technologies.

So some of these again are things we would have to discuss in a different venue, but we have excellent collaboration, particularly with organizations, like Cyber Command, where we often go into demonstrate and experimental capability and can very quickly turn it into something that transitions to their operational use in the course of a program.

Senator MORAN. Doctor, thank you very much.

Ms. McQuiston, let me follow up with what Senator Shelby was conversing with you about, hypersonics. Can you please provide an update on the industrial base partnerships that DOD has entered into to support carbon-carbon manufacturing initiatives?

Ms. MCQUISTON. Additive manufacturing for hypersonics has been key. In fact, it's been a real enabler in commercial technologies, as well. It's not only sort of the breakthrough technology for hypersonics, but it's also being used in the automotive industry to really dramatically change fuel efficiency.

I personally have not had the time to go through other agreements that we may have within the industry, but I would welcome that opportunity to come back to you with the details on that.

Senator MORAN. I'd welcome further conversations with you.

As our hypersonic batteries come online and we begin to manufacture hypersonic missiles to scale, do we have the industrial base capacity to manufacture at scale?

Ms. MCQUISTON. I believe we do. I believe that we are up for the challenge and can meet it.

Senator MORAN. So what are the challenges that we have in ramping up our production?

Ms. MCQUISTON. Well, right now, we have a roadmap as to where we're moving it for fielding and production use. It is moving ahead and I'm unaware of any specific challenge that we might have right now.

Senator MORAN. I'd appreciate additional conversation with you. Maybe we can have a meeting or——

Ms. MCQUISTON. I think in another venue we could actually get into more detail, exactly.

Senator MORAN. Thank you. Let me ask a final question, this one about space. I now co-chair the Senate's Space Force Caucus, and I'm the Ranking Member of the CJS (Commerce, Justice, Science), the NASA (National Aeronautics and Space Administration) Appropriations Subcommittee, along with Senator Shaheen.

How is your office working with commercial and government partners to make certain that satellite constellations remain secure from cyber and kinetic attacks?

Ms. MCQUISTON. That's very important to us in looking at that. In fact, recently we had used adopted commercial processes which often in the past financial institutes would use to basically open up a satellite opportunity to hack-a-sat, we called it. So you could have hackers try to break in and disrupt options of the satellite.

This has actually been a very good learning platform and to strengthen our own security within our satellite systems. So, again, adopting both commercial and putting together new technologies for defensive security operations within LEO and our satellite operations is going to be a very high priority for the Department of Defense.

Senator MORAN. Thank you. Mr. Chairman, thank you.

Senator TESTER. Thank you, Senator Moran.

Senator Baldwin.

Senator BALDWIN. Thank you, Mr. Chairman.

Our military is reliant on lithium ion batteries to power critical systems, including plant energy-intensive applications, like advanced radars and sensors. Unfortunately, we are also reliant on foreign companies, including in China, for components that go into these batteries.

We have really struggled to stand up domestic R&D capability to discover and validate new battery chemistries and technologies that would improve performance and safety and reduce costs for both military and commercial applications.

Currently, most of our innovation and resulting intellectual properties have been in Asia. On this latter point, I believe the U.S. needs to build a robust independent commercial cell development and testing capability to support advanced battery technologies needed for our military systems and commercial applications, like electric vehicles and electric grid storage.

Ms. McQuiston, I would like to hear your thoughts on how DOD can make investments to address these challenges and support next generation battery technology.

Ms. MCQUISTON. Safe uses of lithium batteries actually has been a priority for the science and the university work that we've been doing.

That said, battery technology has quite a range within the military, from the amount of batteries that need to be in the field to moving forward with high-power weapon systems.

I would say that battery technology is going to be key for micro grids that we would need at basing and forward sites. I think batteries are a priority. The science and the materials can actually move forward, I think, if we focus our energies.

DARPA is always good at looking at materials and batteries have always been a capability that they've had at modernizing and perhaps inventing new technologies and safer approaches at higher density, energy density.

Senator BALDWIN. Thank you. I've been advocating for strengthening our Buy America policies, including extending domestic content requirements down the supply chain to support the U.S. industrial base. Those efforts are critical but more focused on the acquisition side of DOD investment policy.

I also believe that we need to do more on the research, development, and innovation side, those areas, Ms. McQuiston, over which you have responsibility.

If we look at the pacing threat of China, let's say in the shipbuilding sector, DOD has reported that it has become the top ship-producing nation in the world and produces most of its critical components, like engines, weapons, and electronic systems.

The Chinese Government is investing massive sums to ensure that those components are high-performing and manufacturable at scale.

I believe that the DOD using existing authorities should provide funding to our domestic shipbuilding industrial base, particularly small- and medium-size businesses, to increase their technical capability, grow their capacity, and improve their manufacturing technology, design, and engineering processes.

Across the DOD research and engineering enterprise, what are your priorities for supporting the industrial base and what programs and investments will you make to support the technological competitiveness in manufacturing capacity of our critical defense suppliers?

Ms. MCQUISTON. Manufacturing is key to a number of technologies across the board and being able to modernize and work with manufacturing and make investments is also key to our economic security.

When you look at manufacturing, it's not only for perhaps DOD enabling capability and scale, but it's also to derisk some of the newer technologies that are required, and we have a number of manufacturing programs in this area that we're moving forward, but we are working with aspects of this from 5G and the micro electronics side straight through to materials, battery technology, as we just discussed, and moving into a program that we have at a university that's working in materials that would be supported for difficult marine environments.

So I concur with you on the need for manufacturing.

Senator BALDWIN. Thank you. Mr. Chairman, I yield back.

Senator TESTER. Thank you, Senator Baldwin.

Senator Shaheen.

Senator SHAHEEN. Thank you, Mr. Chairman, and to Ms. McQuiston and Dr. Tompkins, thank you both very much for your work and for testifying today.

I appreciate the importance of DARPA and of our investing public dollars in innovation and research for our national security, but you alluded to this, I think, earlier, Ms. McQuiston, when you talked about the private sector, and the fact is much of the innova-

tion that we benefit from comes from the private sector, is that correct?

Ms. MCQUISTON. I would say that it's quite an engine for us in innovation, absolutely.

Senator SHAHEEN. And one of the programs that has been really successful in promoting small businesses to do that kind of research is the SBIR (Small Business Innovation Research) Program. Can you speak to how important you think that is?

Ms. MCQUISTON. I think it's very important. You know, SBIRs and STTRs (Small Business Technology Transfer) have been quite an engine for us economically and moving investments forward in this area can have a great net gain in the economy, as well.

Small businesses from the investment side are 22:1 return on the DOD investment. So anything we can do to encourage and bridge the gap, so to speak, between defense needs and small business capabilities will be critical. We have a protégé program going forward with large companies so that the smaller companies can sort of be able to contribute in a way that's more meaningful to the DOD mission.

We are also looking through DIU (Defense Innovation Unit) to bring on more small businesses and non-traditional performers, to bring capability to the warfighter' mission. So I think that's a huge focus.

We have to be able to work at the speed of commercial flexibility because we don't want to just be able to understand what their technology is, we need to be able to capitalize on it and field these systems for the warfighter. So that's going to mean that we have to move at speeds that are within a commercial timeframe. So that's going to be critical in not only encouraging small business but actually being able to retain fielded systems and the support of growing our economy with small businesses.

Senator SHAHEEN. Well, thank you very much. We extended the SBIR Program or reauthorized it for 5 years back in 2017, but that means it's going to expire again in 2022.

So, Mr. Chairman, I would just say based on what we've heard and what we know is significant about the SBIR Program, we should start from now to extend/reauthorize that, and I would argue we should reauthorize it permanently. So thank you.

Can you speak to what happens when we develop innovative technologies that are then adopted by our adversaries and used to undermine the United States? How do we prevent that? What can we do to better make sure that what we're doing in innovation doesn't get pirated by our adversaries?

Ms. MCQUISTON. Well, I think securing our technology is key. WE have the TAPS (Transition Assistance Program) Program, which is working to make sure that our research and development dollars are secure, looking at university funding and having transparency in an area of research that we think is critical, so that we understand other areas of funding that are coming in.

We also want to carefully work with scientists and researchers who we do not feel that there's an individual that could be a risk to the performance there, but I do believe we need to be smart and strategic about what we need to protect and keep the pace of surprise moving forward. That's the great thing about DARPA because

there's always a new frontier and there'll always be, you know, people adopting and catching up, but if we're always moving ahead, we make the process of catching up that much more difficult, though security, I think, especially at the rate of cybersecurity and really protecting our own investments, has got to be in the forefront as we move forward, but to do it smartly.

Senator SHAHEEN. Thank you. I only have a few seconds left, but I did want to ask you because you were talking about the challenge of legacy systems and innovation and how to balance phasing one out or addressing new innovative technology.

When we do that, is it usual that contracts are awarded when we've got a technology that has not been proven or tested or fielded in any way? Can you answer that?

Ms. MCQUISTON. Off the top of my head, I would say that we definitely need to make sure that we have trust in the system before it's fielded which is why we've stood up three offices between the Systems Engineering Office at SCO (Strategic Capabilities Office), DIU, with the Experimentation and Fielding, and then Emergent Technology Capability and working with that to demonstrate its capability.

But in some technologies, it can move quite rapidly. So if we're looking at evolving technologies, such as in cybersecurity, we should have a rapid pace at being able to develop, test, and field this capability rather quickly.

Obviously other technologies would take more time and testing, but we have to be flexible in how we approach the technology, which goes back to innovation, and it goes back to what I was saying in the beginning. You have to be doing the right thing and doing it correctly, but you have to adopt the flexibility in the program to account for the type of technology you're managing with the goal of fielding it as rapidly as you can.

Senator SHAHEEN. Thank you. Thank you, Mr. Chairman.

Senator TESTER. Thank you, Senator Shaheen.

Senator Hoeven.

Senator HOEVEN. Thank you, Mr. Chairman. Appreciate it. And thank you for the opportunity to meet with you today.

Secretary McQuiston, earlier you mentioned SDA, the Space Development Agency, working with Grand Forks Air Force Base. We appreciate that very much. As you know, we've worked very diligently to develop all things unmanned aviation there and obviously that whole link and the development with the satellites is incredibly important. We think we have an absolutely unique resource there. So we appreciate it and we appreciate the working relationship we have with the Space Development Agency.

We think that SDA needs to continue, to accelerate the development of technology for the warfighter. We think that's incredibly important.

So tell me, how will you ensure that SDA can provide innovative and independent support for our warfighters, even as you transition to Space Force in October of 2022, and obviously we're very concerned about supporting that effort because we think it's very worthwhile but also because we think it's important. Grand Forks Air Force Base is part of that.

Ms. MCQUISTON. Yes, I believe keeping in place the spiral development process that they've put in to work at commercial speeds and to very quickly be able to field capability will be the best way to work with this development of technology for space.

I think it's already a proven pace that you see with commercial entities and I believe that what we have started right now with the Space Development Agency will prove itself by their 2-year cycle time for being able to update capabilities that we're bringing to the warfighter.

Senator HOEVEN. Good. And we appreciate very much the working relationship that we've had with you.

Is there anything that we can do at this time that you think is particularly helpful to make sure that we continue to advance this initiative?

Ms. MCQUISTON. Well, we appreciate your support for this effort and that is invaluable in itself. So thank you.

Senator HOEVEN. And same questions for Dr. Tompkins. Did you have anything that you would add?

Dr. TOMPKINS. I agree with Ms. McQuiston regarding the support and appreciation for all the support you've provided, and DARPA works very closely with the SDA specifically in developing new technologies which then derisk, you know, elements of the technology for them to deploy and we look forward to seeing the fruition of some of those efforts in the near future.

Senator HOEVEN. Good. And again we want to make sure that we continue to offer any and all assistance so that that development continues as it is. We think it's incredibly important.

Back to Ms. McQuiston. Now talk to me in terms of the next step, which is not just that communication with the satellites, but then also the communication between satellites and unmanned aviation, and again that's one of the things that we've developed in a way like no other, and obviously that's going to be an incredibly important part of this whole effort.

So talk to me about development on that second step, as well.

Ms. MCQUISTON. Yes. Looking at being able to have the battle space information, backbone in place, we have JADC2 as a program, and we also have AB2 moving forward, and looking at the information moving within the network and able to be used between ground and space will be critical. So the network and the data availability will actually be quite a platform for innovation and being able to constantly grow our capabilities at a rapid speed for the warfighter.

Senator HOEVEN. Yes. And tell me a little bit more about that interagency cooperation because one of the things we've done is we've broken down barriers. I mean, we're working with everybody. It's not just at the State and local level but all the different agencies, including NASA, Department of Defense, FAA, and everybody else.

How are you working to make sure that you're integrating all of the agencies in there, as well, in this effort?

Ms. MCQUISTON. We are working with all the agencies, and I believe the relationships are very good because everybody wants to move forward in this area. So I would say right now, we keep the pace moving forward.

Senator HOEVEN. Great. Thank you so much. And, Dr. Tompkins, anything else that you might want to add on that issue?

Dr. TOMPKINS. I completely agree with everything Ms. McQuiston has said. I think in the interest of time, I'll leave it there just with our thanks and our excitement about the future.

Senator HOEVEN. I just want to thank both of you for your innovation and your creativity and your strong leadership. We truly appreciate the working relationship. Thanks so much, and we'll continue to support your efforts in this very important area.

Ms. MCQUISTON. Thank you.

Senator TESTER. Thank you, Senator Hoeven.

Just one more question from me and then we'll close out. This is for both of the testifiers and it's been talked about with previous questions. I think it's important that we add value by tapping into academia and private sector, small business and large business.

From your guys' perspective, has there been greater participation by folks outside your agencies over the last years, has it been pretty static, or less?

Ms. MCQUISTON. I think there's been larger participation and mostly because of the outreach programs that we've put together, especially through the Defense Innovation Unit, because we're seeing a lot of non-traditional companies coming in, and we're seeing an increase of small business that are excited to work with the Defense Department and able to demonstrate their capabilities, but more is required.

Senator TESTER. Okay. Dr. Tompkins?

Dr. TOMPKINS. Yes, similarly. Of course, DARPS's funding goes entirely to those external partners. So what we would be tracking is sort of the diversification of that pro forma space and what we've looked for are organizations that have never worked with DARPA before, have never worked with the DOD, and through those kinds of outreach activities that Ms. McQuiston just mentioned, we are seeing that increase and we hope to see it even more.

To get the best ideas and to get the best capabilities we need to be reaching the broadest possible and most diverse pro forma pool possible.

Senator TESTER. Do either of you see any existing barriers to working with your particular agencies and if you do, are those barriers things that you can break down or do you need congressional help?

Ms. MCQUISTON. Well, right now at R&E, launching the Innovation Steering Group, I'm looking for areas of continual improvement and I think that we will be able to articulate sort of changes that need to take place internally in order to become more rapid in an adaptation of technology and to be more flexible in being able to do that.

Senator TESTER. So no barriers?

Ms. MCQUISTON. At this time, I would say it's a matter of rolling up our sleeves.

Senator TESTER. Okay. Dr. Tompkins?

Dr. TOMPKINS. The one thing I would suggest is that we're going to be taking a hard look at some of the sort of potential barriers for organizations that have traditionally worked with the Depart-

ment of Defense, looking at the cost of compliance, and looking at sort of the murkiness of how organizations can successfully comply.

I think this is particularly tough on smaller businesses, commercial organizations that haven't worked with Defense before, and many different classes of universities where the amount of overhead that they can afford to put in to being able to be sufficiently compliant can be really challenging and so we would be looking for ways to sort of meet them in the middle and find ways to make it easier for them to participate while still being fully compliant with our requirements.

Senator TESTER. Okay. Thank you.

Senator Shelby, do you have anything you wanted?

Senator SHELBY. I have nothing else.

Senator TESTER. Okay.

Senator SHELBY. We do look forward to some classified hearings with this group because I think it's very important.

Senator TESTER. We will make sure that our staffs together and make that happen.

I just want to express my appreciation for the testimony that was presented here today.

ADDITIONAL COMMITTEE QUESTIONS

Senators need to know that they may submit additional written questions and we would ask you to respond to them in a reasonable period of time.

[The following questions were not asked at the hearing, but were submitted to the Department for response subsequent to the hearing:]

QUESTIONS SUBMITTED TO MS. BARBARA MCQUISTON

QUESTIONS SUBMITTED BY SENATOR JEANNE SHAHEEN

Question. Ms. McQuiston, the Department has been working to improve domestic manufacturing for semiconductors and "microelectronics" through a number of initiatives, including through the National Security Technology Accelerator. At the same time, the Department has stated that is aware of the threats posed by overseas control of printed circuit board manufacturing.

Does the Department consider Printed Circuit Boards (PCBs) to be microelectronics" within the scope of existing funding authorities?

Answer. Yes, the Department considers printed circuit boards to be critical for higher level assemblies for microelectronics, but they are not addressed by the effort "access to State of the Art (SOTA) Microelectronics" in the Trusted and Assured Microelectronics program. The issues surrounding Printed Circuit Boards are industrial base related, and are being addressed by the Under Secretary for Acquisition and Sustainment in coordination with the DoD PrCB Executive Agent.

Question. How does the Department intend to encourage the reshoring of PCB manufacturing capabilities?

Answer. The Department is developing strategies for re-shoring critical microelectronics, including printed circuit board technology products with the help of the DoD Executive Agent for Printed Circuit Boards. Partnership with the interagency, especially the Department of Commerce with respect to infrastructure funding associated with the CHIPS Act, will ensure DoD unique requirements and demand are included in any execution plan.

Question. Ms. McQuiston, I understand that the Army recently awarded a fixed price Production Agreement for the Integrated Visual Augmentation System (IVAS) using Other Transaction Authority (OTA). However, this technology has not completed full testing or fielding for its night vision capabilities.

Could you describe the importance of testing and fielding for night vision technology in particular?

Answer. Fundamentally, the purpose of Test & Evaluation (T&E) is to enable the DoD to acquire systems that support the warfighter in accomplishing their mission. To that end, T&E provides engineers and decision makers with knowledge to assist in managing risks; to measure technical progress; and to characterize operational effectiveness, operational suitability, interoperability, survivability (including cybersecurity), and lethality. This is true for all technology acquisitions including for night vision technologies.

Question. How might fielding equipment that has not gone through rigorous operational testing impact the end user?

Answer. Fielding technology prior to operational testing introduces risk and potentially compromises the reliability and value of the technology fielded. Integrated testing, and the sharing of information across Developmental Test and Operational Test provides necessary data for the operational test agency to evaluate operational effectiveness, operational suitability, and overall mission capability. While IVAS did not conduct an initial operational test and evaluation (IOT&E), they did undergo an Operational Assessment. In this instance, the IVAS system milestones and fielding decisions are made by the Service Acquisition Executive, and therefore R&E would need to defer to the Army on their programmatic decisions.

QUESTIONS SUBMITTED BY SENATOR JERRY MORAN

Question. In order to achieve a multi-band/multi-orbit resilient and redundant enterprise architecture, leveraging non-LEO SATCOM assets is essential.

What are your plans, if any, to leverage Medium Earth Orbit SATCOM capabilities?

Answer. Medium Earth Orbit (MEO) SATCOM capabilities are actively leveraged from the commercial space sector via the procurement activities of the Commercial Satellite Communications Office (CSCO), at the direction of the Chief of Space Operations, United States Space Force (USSF), and in accordance with public law. USSF CSCO is the sole authority for procurement of said services for the Department of Defense (DoD) and satisfies COMSATCOM requirements on behalf of the Combatant Commands, the Services, other DoD and Federal agencies, as well as NATO and FVEY partner nations. Currently, USSF CSCO has approximately 18 MEO-based task orders awarded to the commercial space sector on behalf of DoD and others, providing SATCOM services in various geographic Areas of Responsibility.

Question. The research, development, and production of hypersonic missiles will continue to be a major strategic priority for the Department of Defense.

Can you please provide an update on the industrial base partnerships that the DoD has entered into to support carbon-carbon manufacturing initiatives?

Answer. The Department of Defense Manufacturing Technology program has engaged the carbon-carbon industrial base through multiple investment mechanisms. The Manufacturing of Carbon-Carbon Composites for Hypersonic Applications Initiative has ongoing projects to improve the automation of 2D and 3D processing of carbon-carbon materials. The Manufacturing Innovation Institute network has issued two Manufacturing Challenges to their respective networks to address additive manufacturing techniques for Hypersonic applications, high-temperature Composites, integrated computational materials engineering tools, and advanced manufacturing methods specifically for Hypersonic applications.

Additionally, the Department's Defense Production Act Title III authorities allow opportunities to invest in industrial capabilities such as carbon-carbon manufacturing. In particular, there is a request for proposals for Ultra-High and High Temperature Composite materials open now, which allows our industrial partners to be considered for funding for manufacturing initiatives.

Question. As our hypersonic batteries come online and we begin to manufacture hypersonic missiles to scale, do we have the industrial base capacity to manufacture at scale?

Answer. The Department is working with industry to rise to the challenge of producing hypersonic missiles at scale. R&E has partnered with A&S on a deep dive effort to assess the state of the current and future industrial base. This will help address current Service program needs, and pave the way to have a responsive industrial base to meet future requirements. The Department is using the results of this deep dive to inform the decisions necessary to build at scale, but a number of challenges still remain, particularly relating to supply chain management and supplier capacity. Providing a clear demand signal to our industry partners, in the form of validated requirements and steady procurement, will provide them with the confidence and business case to invest in their sub-tier suppliers and internally build capacity necessary for full scale hypersonic production.

Question. What are the challenges to ramping up production?

Answer. The challenges to ramping up hypersonic production are not unique—workforce and talent, data management, long lead production, and capacity and testing bottlenecks. However, they are exacerbated by the increased complexity of the technology and systems necessary to enable these game changing weapons that provide the Department with transformational capability. As these programs are still in development, their configuration and manufacturing processes are new competencies for industry. Some of the manufacturing processes are highly manual and labor intensive, and require specialized skills. Many need to be transitioned to industrial partners with sufficient throughput, automation, facilities, and technical understanding to produce reliably at scale.

QUESTIONS SUBMITTED TO DR. STEFANIE TOMPKINS

QUESTIONS SUBMITTED BY SENATOR RICHARD J. DURBIN

Question. Climate change is one of the top issues facing our nation, and both President Biden and Secretary Austin have made clear that we must address climate change as a national security issue—one that impacts the resilience of DoD facilities and operations. We must also invest in power and energy R&D to improve performance at our installations and optimize military capability. And this past year, the COVID–19 pandemic has made clear that we must also support research and development when it comes to public health and public agriculture, and the intersection of climate change, pests and diseases, food security, and more.

Please provide an overview of DARPA's public health and public agriculture research that can help ensure we are better prepared against a future pandemic.

Answer. DARPA is currently funding several public health and agriculture research efforts that tackle current limitations in preparation against a future pandemic. Through the Defend Against Crop System Attack program, technologies are being developed to protect staple crops, especially mature plants, that are particularly vulnerable to the most severe threats relevant to disease and climate change. The Pandemic Prevention [1] program is focusing on novel methods to accelerate medical countermeasure discovery, pre-clinical testing, and manufacturing. Pandemic Prevention will enable an integrated therapeutic development platform that leverages state-of-the-art technologies to prevent disease outbreaks. The Deployable Medical Countermeasures for Warfighter Readiness program will make nucleic acid-based medical countermeasures available to the warfighter where and when they are needed. The Preventing the Emergence of Disease (PED) program is investigating how animal pathogens are transmitted to humans and exploring novel approaches to prevent these events. The Expanding Human Resiliency program aims to maximize warfighter resiliency by leveraging the signals of the human microbiome to improve physiology. This program will develop new technologies to control and manipulate the microbiome and reduce attraction and feeding of insect vectors, such as mosquitoes, that carry disease.

DARPA received and has obligated $113 million in CARES Act funding. These funds have been used to accelerate the development and deployment of technologies for the prevention, diagnosis and treatment of COVID–19. Activities and impacts include the following:

—Diagnostics ($18.0M): DARPA research is producing tests that offer earlier, more sensitive, and widely distributable diagnosis of SARS–CoV–2-infected patients.

—Novel Prevention and Treatment Approaches ($64.0M): DARPA is rapidly screening previously approved drugs using methods such as organ-on-a-chip systems and using AI and machine learning methods.

—Pharmaceutical Supply Chain ($29 million): DARPA researchers are developing and commercializing technology that directly addresses supply chain vulnerabilities to enable an end-to-end, deployable, and scalable capability for the production of medicines made from readily available ingredients that can be sourced within the U.S.

—Environmental Monitoring ($2 million): DARPA is developing and enabling a persistent, broad-scale screening system to detect the presence of the SARS–CoV–2 virus.

Question. We lack robust surveillance systems to identify new pests and diseases and track where they are moving. How can DARPA fix that?

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[1] All programs named/cited refer to the Research and Development Descriptive Summaries (RDDS) from the Department of Defense fiscal year 2021 Budget Estimates.

Answer. DARPA focuses on developing technologies to rapidly detect and characterize threats, prevent surprise, and maintain force readiness. Several programs at DARPA focus on creating novel detection platforms for rapid identification of potential pathogens and biosurveillance of animal disease transmission. The Preventing the Emergence of Disease (PED) program is investigating how animal pathogens are transmitted to humans and exploring novel approaches to model, predict, and prevent these events. Promising intervention approaches will be developed to prevent viral species jumps from animal reservoirs to humans. Predicting such jumps is a key capability to mitigating outbreaks in human populations. The Forensic Indicators of Threat Exposure (FITE) program is developing a field-deployable resource for indicators of an individual's exposure history. This program has already supported COVID–19 Health Action Response for Marines (CHARM) by providing rapid delivery of accurate diagnostic results for Marine recruits to ensure training continuity at Parris Island. The Biology for Security (BIOSEC) program seeks to investigate novel approaches to address the DoD need for rapid detection of unknown and/or emerging biological threats by identifying pathogens based on specific behaviors, such as how they interact with and are toxic to host cells. Advances in this area will produce a completely new capability to assess the emergence of pathogens and to detect pathogens that can evade detection by traditional methods. The Gene Editing Enabled Diagnostics & Biosurveillance program will develop fieldable, low-cost gene editing based diagnostics for rapid, specific, sensitive, and multiplexed detection of biological threats in military and public health scenarios. The distributed biosurveillance device will deliver the strategic awareness needed to prevent outbreaks of known diseases, while having the flexibility to quickly detect new emergent biothreats, thereby serving as a firebreak and significantly contributing to DoD humanitarian and stabilization efforts.

QUESTIONS SUBMITTED BY SENATOR JERRY MORAN

Question. Many experts are concerned about future animal pandemics threatening U.S. agricultural systems, affecting trade, jobs and rural communities. Many areas of the world are currently facing African Swine Fever—it has now spread from Africa, to Asia and Europe. There is a strong likelihood that the virus will eventually arrive in the US, which could be devastating to pork producers and processors, as well as to corn and soybean growers who provide feed. Just as in the COVID response, we will need coordinated public private partnerships (PPP) to drive vaccine development and affordable diagnostics. We will also need to increase our surveillance capabilities including platforms to track disease threats. These tools will not only help us protect our agriculture and food producers, but will also create systems to prepare us for future biological threats that could materialize in the coming years.

For big challenges in agriculture that require urgent responses, such as protecting our agricultural and food systems from the impacts of climate change and bioterrorism, do you see the need for increased investments in agricultural research and a role for PPPs in prepare us for future pandemics?

Answer. DARPA is currently pursuing research investments that offer the ability to stabilize vulnerable coastal areas from erosion and flood-related disasters as well as identify, track, and respond to emerging agricultural threats expected to develop on faster timescales. This research should lead to developments that assist the Department of Defense in risk and vulnerability mitigation strategies related to vulnerabilities that reside in the global food system. The development of capabilities that provide early detection and identification of emerging threats and/or disruptions to the global food system will likely benefit from coordinated public private partnerships that ensure broadest dissemination and sharing of data related to global food system security.

Question. Your office is focusing heavily on technology transition projects to improve cyber defenses for the Department and its industrial partners.

Can you please describe how MOSAICS and other related cyber initiatives will not only support the Department's cyber defense, but the industrial partners that are critical to our national security?

Answer. DARPA's cyber initiatives support both the Department's cyber defense and the industrial partners that are critical to our national security.

DARPA is developing the computing, networking, and cyber security technologies required to protect and enhance systems that are essential to DoD, USG, and U.S. civil infrastructure.

Information technologies are a focus of intense computation with both peer and non-peer adversaries, and this competition will be ongoing.

Systems. DARPA programs are developing the technologies to enhance the security, resiliency, and adaptability of complex software systems. Enhanced security and resiliency are essential to meet increasingly sophisticated cyber threats. Adaptability is needed to rapidly assimilate new capabilities in an evolving operational environment. Systems with rich supply chains pose particular challenges. Our work includes not just techniques for the development of new systems, but also, importantly, techniques that can enhance security and adaptability for a wide range of existing systems.

Operations. DARPA programs explore data-intensive analytics for enterprise cyber defense, including fusion to support attribution of attacks for targeted response, new confidentiality techniques based on applied cryptography applicable to privacy and Internet Freedom, resiliency techniques to enable resilient recovery from attacks, and social engineering defense for phishing attacks. Programs also enhance the capability of cyber operators through improved data sourcing and analytics, tools and frameworks, and operator experience design, including environments for command centers.

In addition to developing information technologies, DARPA works to transition the results of its R&D to operations through applications such as the following:

—*Critical Infrastructure Cybersecurity:* With regard to cyber-defense of the power grid, DARPA-developed cyber tools and a test bed were transitioned to the Department of Energy and commercial utilities under a MOA between 16th Air Force, U.S. Cyber Command, and DARPA that establishes a Joint Electric Power Range (JEPR) at Fort Carson. The JEPR will be an enduring national resource for power grid cyber resilience experimentation and development.

—*Cyber Attribution:* DARPA-developed cyber analytics were used to generate timely, accurate threat information regarding malicious Russian cyber activities. This information was shared with partners at the FBI Atlanta and Pittsburgh field offices, contributing to the indictment of six GRU personnel associated with a worldwide destructive malware campaign and the remediation of that malware campaign in U.S. and allied critical infrastructure.

—*Cyber Protection for Combat Vehicles:* DARPA-developed technology has been selected by the Army Combat Capabilities Development Command Ground Systems Vehicle Development Center to provide cyber protection to their Next Generation Combat Vehicle. The technology will be matured to TRL–6 for Army ground vehicle environments under this transition.

—*Cyber Command and Control:* DARPA initiated the Plan X program in 2013 to develop a command and control platform for military cyber operations. Plan X technology was transitioned to the Strategic Capabilities Office in July 2019, where it was further developed under Project Ike, and has now been transitioned again, this time to the Joint Cyber Command and Control (JCC2) program management office.

SUBCOMMITTEE RECESS

Senator TESTER. The Defense Subcommittee will reconvene on Tuesday, April 20, at 9:30, for a hearing on the Defense Health Program.

With that, this subcommittee stands in recess.

Ms. MCQUISTON. Thank you.

[Whereupon, at 10:55 a.m., Tuesday, April 13, the subcommittee was recessed, to reconvene at 9:30 a.m., Tuesday, April 20.]